Impact of fragmentation and plantations on rainforest birds in the Anamalai hills, southern Western Ghats, India

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SUMMARY

The conversion of large tracts of tropical rainforest to smaller patches embedded in a landscape matrix of human-altered habitats such as plantations is one of the serious and reigning concerns in the field of conservation biology. Here, I describe the effects of rainforest fragmentation and conversion to tea, coffee, and *Eucalyptus* plantations on bird communities in the highly man-modified landscape of the Anamalai hills in the southern Western Ghats hill ranges, India. Systematic point-count sampling for birds and habitat sampling for vegetation description were carried out in the three plantations types and in 13 rainforest fragments ranging in area from 0.3 ha to 2,600 ha. A total of 106 bird species were recorded, including 75 typical rainforest species and 31 species of open-country and drier forests that had colonised disturbed fragments and plantations. Total bird species richness was higher in medium-sized fragments (10−100 ha), due to the entry of these widespread open-country species, along with the persistence of many rainforest species. Null models of passive sampling in relation to area or abundance did not predict bird species richness. Rainforest bird species richness instead increased virtually log-linearly with fragment area, with substantial decrease in species richness below a fragment area threshold of 10 ha. In addition, the structural development of rainforest canopy and vertical foliage distribution had positive effects on rainforest bird species. Medium-sized fragments, particularly with relatively undisturbed vegetation, held significant populations of rainforest bird species, including endemic species, and are important repositories and refuges in the landscape for birds. The similarity in bird community composition between sites was positively related to their similarity in tree species composition, and negatively with their difference in area or physical distance separating them. The compositional changes showed a nested-subset structure, indicating possible differential extinction of species in relation to changing area and habitat. Plantations, particularly of tea and *Eucalyptus*, detrimentally affected rainforest birds, although a number of rainforest birds thrived in shade-coffee plantations. Although 17 rainforest bird species did not occur in any plantations, those species that did occur also persisted or occured at higher densities in small and medium-sized fragments in the landscape. The conversion of shade-coffee to tea plantations is a matter of concern for bird conservation in the region and needs to be offset through commercially viable incentives. The study also highlights the value of rainforest fragments and the need to reverse degradation through active efforts at restoring tree species composition and rainforest structure for rainforest bird conservation.

1 INTRODUCTION

1.1 Conservation issue

Habitat fragmentation, defined simply as the reduction in area of habitat and its distribution in smaller and more isolated patches, is one of the most serious conservation issues to emerge worldwide in recent years (Noss and Csuti 1997). This is of critical concern to conservation biologists, particularly in regions with tropical rainforest, which are the greatest living treasuries of biological diversity on Earth (Richards 1996, Wilson 1992), as the most severe threats and human onslaught are also often borne by these forests. Estimates reveal that between 1979 and 1989, about 150,000 km² of tropical rainforests were lost around the world to various forces of deforestation and most previously pristine landscapes now contain only remnant fragments and secondary forests (Brown and Lugo 1990, Myers 1991, Laurance and Bierregaard 1997, Whitmore 1997). This undoubtedly contributes significantly to the present global extinction crisis (Wilson 1992). As large forest tracts are converted to 'islands' in a 'sea' of altered and developed areas, the survival of many plant and animal species will hinge upon their ability to persist in human-modified landscapes and on our direct efforts to conserve and manage these species and their habitats.

The Western Ghats hill ranges of India typify many of these conservation problems. This hill chain is recognised as one of the eight 'hottest hot spots' of biological diversity in the world (Myers *et al.* 2000) and among the 200 globally most important ecoregions (Olson and Dinerstein 1998). Among the global biodiversity hotspots, the Western Ghats and Sri Lanka rank third in terms of the number of endemic vertebrates/area ratio (species/100 km², Myers *et al.* 2000). For birds, the region

has been recognised as an Endemic Bird Area with 16 species of restricted-range birds, including 12 of near-threatened conservation status (Stattersfield *et al.* 1998). According to a recent evaluation, the Western Ghats supports populations of one endangered, three vulnerable, and seven near-threatened bird species, of which all but two inhabit tropical rainforests (BirdLife International 2001).

On the other hand, the Western Ghats faces severe threats from human disturbance due to deforestation, developmental activities, conversion to plantations, and habitat fragmentation (Nair 1991). Menon and Bawa (1997) estimated that between 1920 and 1990 forest cover in the Western Ghats declined by 40%, resulting in a four-fold increase in the number of fragments, and an 83% reduction in size of forest patches. This is not surprising given that this region is one of the hotspots with the highest human population density (Cincotta *et al.* 2000).

One of the major causes of forest fragmentation in the Western Ghats is the spread of plantations, particularly tea, coffee, and *Eucalyptus*. The area under plantations is large and growing. The area under tea plantations in the south Indian states increased from 74,765 ha in 1987 to 87,993 ha in 1998. In 1998, this US$ 400 million industry employed over 195,000 people (1999 Statistics of the Tea Board of India). Large areas of *Eucalyptus* plantations also occur with tea as it is used as fuelwood for the factories. Similarly, in 1999–2000, the US$ 500 million Indian coffee industry had plantations over 293,000 ha, almost entirely in southern India. This industry, producing over 170,000 tons of coffee annually and employing over 520,000 people, accounts for substantial non-natural forest canopy cover in the states of Karnataka, Kerala, and Tamil Nadu in the Western Ghats (Coffee Board Statistics 2001).

Recent studies have highlighted continuing threats to tropical rainforest and wildlife species in the Western Ghats (Daniels *et al.* 1995, Kumar *et al.* 1995, Umapathy and Kumar 2000). There is an urgent need to comprehensively study the long-term impacts of such habitat changes and landscape alteration on birds and identify ameliorative conservation measures.

1.2 Conceptual background: Species survival in fragmented landscapes

An enormous literature exists on the effects of habitat fragmentation on plant and animal communities in the tropics (see reviews in Saunders *et al.* 1991, Andrén 1994, Simberloff 1994, Wiens 1994, Turner 1996, Turner and Corlett 1996, Laurance and Bierregaard 1997). Although a comprehensive review is impracticable here, a brief mention of the major mechanisms and hypotheses proposed to explain the effects of fragmentation is provided below.

Island biogeography–area and isolation: Early studies that found species richness to be a function of island or fragment area and isolation explained this pattern in relation to the theory of island biogeography (MacArthur and Wilson 1967, Diamond 1975b, 1976, Newmark 1991). Due to extinction and colonisation dynamics that were a function of species richness, larger or nearer islands were expected to contain a greater number of species than those smaller or further away.

Habitat diversity: Remnant patches do not merely differ in size from larger areas of forest that existed prior to fragmentation. A large number of habitat changes are brought about due to edge effects, microclimatic changes, increased exposure, and human disturbance (Lovejoy *et al.* 1986, Saunders *et al.* 1991). The remnants may also contain only a subset of microhabitats otherwise available in a larger area. Changes in habitat structure or lack of specific microhabitats may be more directly involved in influencing species occurrence or abundance patterns in fragments than other factors (Simberloff 1994). Sites more similar to primary forest in habitat structure and floristics may be expected to contain more similar bird communities (Raman *et al.* 1998).

Landscape matrix effects: Unlike true islands, most forest fragments are not surrounded by a sea of inhospitable or ecologically neutral environments (Wiens 1994). The altered habitats in the surrounding landscape matrix are a source of potential colonists as well as being suitable for colonisation by species that can persist in such habitats. The ability of species to survive in fragments may thus depend on surrounding habitats and whether the species uses such habitats (Stouffer and Bierregaard 1995a,b, Laurance *et al.* 1997, Renjifo 2001).

Differential extinction–nested subsets: Differential extinction of species may lead to the appearance of a nested subsets pattern of species occurrence, where successively larger fragments contain species found in all smaller fragments (Patterson and Atmar 1986, Patterson 1987, Bolger *et al.* 1991, Cutler 1991, McCoy and Mushinsky 1994, Worthen 1996, Wright *et al.* 1998). The pattern may be caused by differential extinction vulnerability attributable to density (Bolger *et al.* 1991) or even the nested occurrence of microhabitats used by the species. Although a great majority of published studies report significantly nested patterns of occurrence of species (Wright *et al.* 1998), there has been considerable debate on which methods are appropriate to assess nested subsets structure (Cutler 1991, Simberloff and Martin 1991, Cook and Quinn 1998, Worthen 1996, Brualdi and Sanderson 1999, Cam *et al.* 2000). In addition, contrasting patterns of nested subsets structure may be shown by different ecological groups of species (Kadmon 1995, Fleishman and Murphy 1999) or in relation to different independent variables such as species richness, area, or isolation (Simberloff and Martin 1991, Kadmon 1995).

Species attributes: The response of birds to fragmentation may depend on specific life-history attributes. Species groups that may be particularly susceptible include large-bodied frugivores and carnivores (Leck 1979, Terborgh and Winter 1980, Brash 1987, Thiollay 1989, Kattan *et al.* 1994), and terrestrial and understorey insectivores (Leck 1979, Stouffer and Bierregaard 1995a, Canaday 1996, Stratford and Stouffer 1999). Other factors that are known to increase vulnerability include high population variability (Karr 1982) and restricted range (Simberloff 1994).

Random sampling: In exploring the effects of fragmentation, it is necessary to test the possibility that the observed patterns may have arisen by chance alone. One mechanism that may produce a positive relationship between species richness and area is random colonisation of fragments, depending on their area (Coleman *et al.* 1982) and/or isolation (Hubbell 2001). As larger fragments are likely to contain more individuals, greater species richness is expected by chance alone (Wiens 1989, Haila *et al.* 1993, Villard *et al.* 1995).

2. OBJECTIVES

This study aimed at understanding the relative influence of the above multiplicity of factors proposed to explain the effects of forest fragmentation and habitat alteration on bird communities. The major questions addressed during the study were:

(i) Are bird species richness and abundance predictable from fragment area and isolation (as expected under island biogeography theory), habitat attributes (habitat structure and diversity hypothesis), or from null models that simulate random colonisation or assembly of species (passive sampling)?

(ii) What is the pattern of species turnover across fragments? Is it predictable from measures of site and habitat characteristics? Do smaller fragments contain nested subsets of species occurring in larger fragments due to differential species colonisation or extinction?

(iii) Are birds that avoid altered habitats (plantations) in the surrounding landscape matrix more susceptible to habitat fragmentation than more generalist species?

(iv) How do different diet-guilds and species categories of birds respond to habitat fragmentation? What is the conservation status of endemic and rare bird species and are they more vulnerable to habitat fragmentation and conversion than other species?

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 *Western Ghats*

The Western Ghats is a 1,600 km long chain of hills running along the west coast of the Indian Peninsula from near Kanyakumari (8° N) at the southern end to the river Tapti in the north (21° N). The chain of hills is interrupted by the 30 km wide Palghat Gap at around 11° N, and a few other minor gaps along its length. This unique biogeographic province (Mani 1974, Rodgers and Panwar 1988) has pronounced north-south, east-west, and elevational gradients, which have profound

consequences for the distribution of plants and animals. The southern end of the Ghats has a short dry season (2 – 5 months) as it receives rain from the southwest (June – September) and northeast (October – January) monsoons. The northern reaches have a longer dry season (5 – 8 months), receiving rain mostly during the southwest monsoon. The average annual rainfall in the evergreen forests ranges from around 1,800 to 7,500 mm depending on the locality (Pascal 1988, Daniels 1992).

Most of the higher hills (1,000 – 2,000 m) in the Western Ghats are found towards the south, between 8° N and 13° N. Pascal (1988) has classified the tropical wet evergreen forests of the Western Ghats into low (< 700 m), medium- (700-1,400 m), and high-elevation (> 1,400) m types. Moist forests, including tropical wet evergreen rainforest, are found largely south of 16° N, particularly south of the Palghat Gap, a region often called the southern Western Ghats. This is also the region that contains higher diversity and a greater number of endemic rainforest plant and animal taxa (Nair and Daniel 1986, Daniels 1992, Vasudevan *et al.* 2001, Ishwar 2001, Ali and Ripley 1983). This pattern is also evident in mammals, where species such as the Nilgiri tahr (*Hemitragus hylocrius*), Nilgiri langur (*Trachypithecus johnii*), and brown palm civet (*Paradoxurus jerdoni*), are confined largely to the southern portion of the Western Ghats (south of 12° N).

3.1.2 *The Anamalai hills*

The Anamalai (which in Tamil, the local language, means the elephant hills) ranges are a major conservation area in the southern Western Ghats. The ranges occur just south of the Palghat gap and are linked with the Nelliampathy hills towards the west, the Palni hills toward the southeast, and the Eravikulam, High Wavy and other ranges towards the south. A number of protected areas span this region, including the Indira Gandhi Wildlife Sanctuary (WLS) in the Anamalai hills, Eravikulam WLS, Chinnar WLS, Parambikulam WLS, reserve forests, and the new Kodaikanal WLS in the Palni hills.

In contrast to most of the other protected areas that contain large areas of tropical dry and moist deciduous forests, and high-altitude shola-grassland ecosystems, much of the key mid-elevation tropical evergreen forest of interest to this study, occurs in the Anamalai hills. Although a significant portion of this occurs in the Indira Gandhi Wildlife Sanctuary (987 km², 10° 12' N to 10° 35' N and 76° 49' E to 77° 24' E), many of the rainforest fragments occur in private lands in the Valparai plateau (see map). The natural vegetation of this region, receiving over 2,500 mm of rainfall annually particularly during the southwest monsoon (June – September), has been classified as mid-elevation tropical evergreen forest of the *Cullenia-Mesua-Palaquium* type (Pascal 1988). The Valparai plateau contains a large area of tea, coffee, and cardamom estates occupying over 130 km² and lying almost in the centre of the above mentioned conservation areas. This area has a small town (Valparai) and a human population of over 200,000 people, mostly estate labourers, scattered across the town and estates.

At least 25 rainforest fragments have been identified so far in the Anamalai hills (Kumar *et al.* 1995, Umapathy and Kumar 2000). Besides two large fragments (2,000 and 2,500 ha) within the Indira Gandhi Wildlife Sanctuary, the remaining rainforests all occur as fragments of 0.3 to 650 ha in size jointly occupying over 2000 ha, much of which is on private land. Thus nearly a third of the rainforests occur as fragments and these are vital for conservation as they contain significant proportions of the native fauna as well as being important for landscape-level connectivity between patches. The plantations and fragments are surrounded on three sides by protected areas that contain significant wildlife populations (see Map). Many species move through this fragmented landscape between fragments, including large mammals such as elephants (*Elephas maximus*), tigers (*Panthera tigris*), leopards (*P. pardus*), and wild dogs (*Cuon alpinus*), and birds such as Great and Malabar Grey Hornbills (bird scientific names in Appendix). The conservation of rainforest fragments is also important as corridors for these wide-ranging taxa (Kumar 2000).

Map of Indira Gandhi Wildlife Sanctuary showing rainforest fragments and surrounding areas

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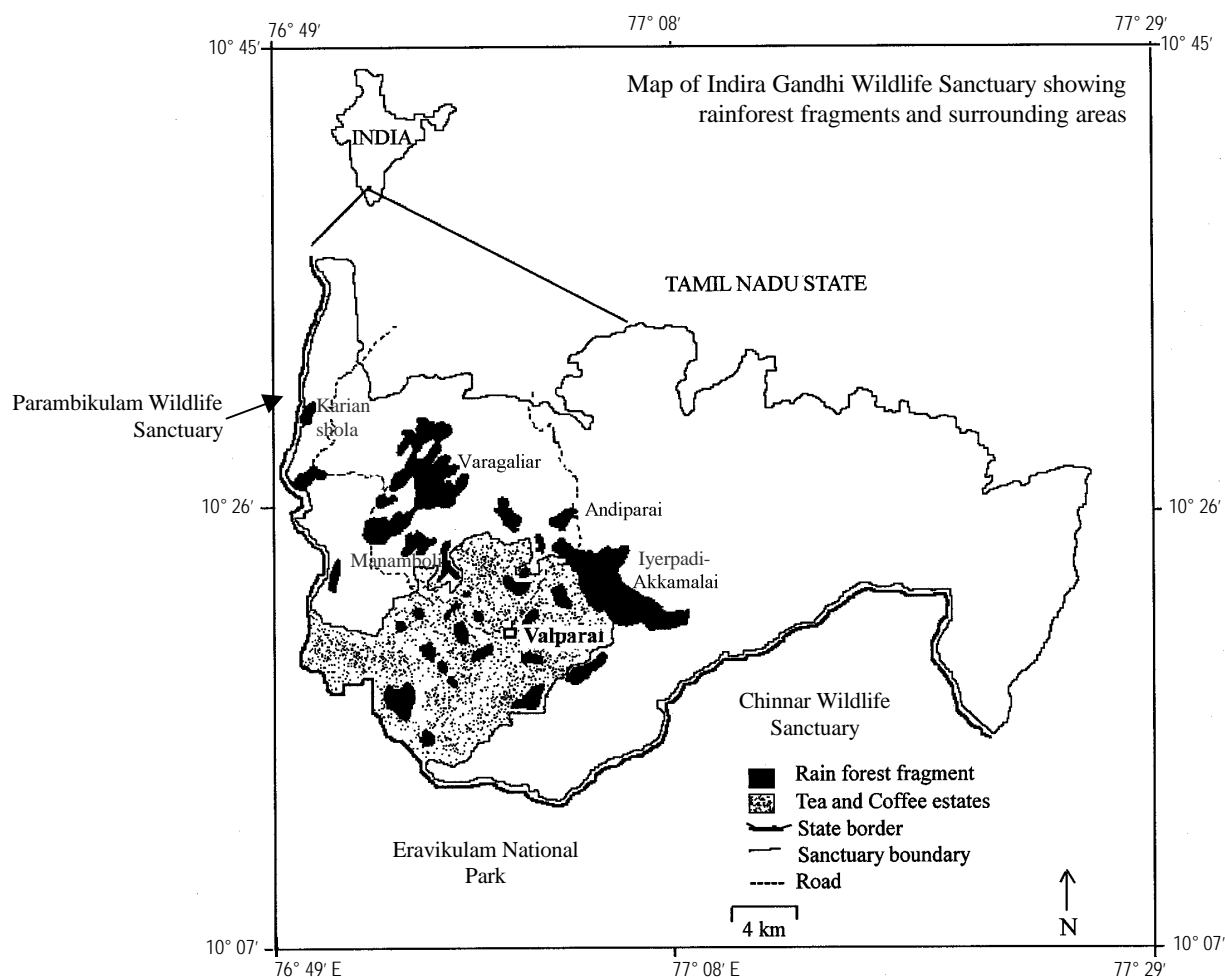
Over 500 species of birds are known to occur in the Western Ghats, of which around 280 species are terrestrial species. A large part of the diversity consists of widespread species that typically occur in the dry deciduous forests. The tropical evergreen forests contain fewer species but a greater proportion of endemic and restricted-range species than similar rainforests in northeastern India (Ali and Ripley 1983, Daniels *et al.* 1992). Moist forests, particularly tropical evergreen rainforest in the southern Western Ghats, is a major habitat for over 100 species of birds, including 13 endemic species (Malabar Grey Hornbill, Malabar Parakeet, Nilgiri Wood Pigeon, Grey-headed Bulbul, White-bellied Treepie, Wynaad Laughingthrush, Grey-breasted Laughingthrush, Rufous Babbler, Black-and-Orange Flycatcher, Nilgiri Flycatcher, White-bellied Blue Flycatcher, White-bellied Shortwing, Crimson-backed Sunbird, common names follow Grimmett *et al.* 1998). Two other restricted range-species that occur in high-altitude grasslands in this region are Nilgiri Pipit and Broad-tailed Grassbird). A number of other rare species with range largely restricted to the Western Ghats and other mountain ranges in the Indian peninsula, Sri Lanka, or the Himalaya, also occur in these tropical rainforests: e.g. Malabar Trogon, White-bellied Woodpecker, Asian Fairy Bluebird, Mountain Imperial Pigeon, Rufous-bellied Eagle, Oriental Bay Owl, Jerdon's Baza, Black-crested Baza, Ceylon Frogmouth), the last two being among the near-threatened species (Collar *et al.* 1994). A total of 218 bird species have been identified in the Anamalai hills (Kannan 1998) and my preliminary work has added another 12 species so far; of all these, around 90 species are typical rainforest birds.

Only the hornbills receive protection under Schedule I of the Indian Wildlife Protection Act of 1972 (Anonymous 1994), although the conservation status of many other species may be equally vulnerable. The 16 species of restricted-range birds in the Western Ghats include 12 of near-threatened conservation status (Stattersfield *et al.* 1998). A recent assessment reports that the Western Ghats supports populations of one endangered, three vulnerable, and seven near-threatened bird species, of which all but two inhabit tropical rainforests (BirdLife International 2001).

3.2 Selection of sampling sites

The area chosen for study was the highly man-altered landscape of the Valparai plateau in the Anamalai hill ranges in the southern Western Ghats. The base camp in Valparai allowed sampling fragments in a 10 km radius. Following Umapathy and Kumar (2000), for the purposes of this study, fragments were defined as patches of relatively intact or degraded tropical evergreen forest that were isolated (except for very narrow corridors, if any) from other such patches by being surrounded by other vegetation types, plantations, reservoirs, or human habitation. Birds were sampled using point counts in 13 rainforest fragments ranging in size from 0.3 ha to 2,600 ha and the matrix of tea

(*Camellia sinensis*), coffee (*Coffea arabica*), and *Eucalyptus* plantations in the Valparai plateau and Indira Gandhi Wildlife Sanctuary (Figure 2.5, Table 1). Eleven fragments were in an altitudinal range of 800 to 1,400 m altitude in mid-elevation tropical evergreen forest (*Cullenia-Mesua-Palaquium* type), while the other two (Karian Shola and Varagaliar) occurred at a slightly lower elevation.

Table 1: Area, location, and matrix surrounding rainforest fragments sampled in the Anamalai hills.

Fragment	Area (ha)	Location	Altitude[a] (m)	Matrix[b]
Kochank 1 (K1)	0.3		1,050	T
Kochank 2 (K2)	0.5		1,053	T, E
Varattuparai 4 (V4)	1		1,020	T, C, R
Varattuparai 1–3 (V3)	7	76° 55' 48? – 10° 21' 21?	1,025	T, C, H
Pannimade (PA)	10	76° 53' 42? – 10° 17' 46?	1,044	T, C, R
Tata Finley (TF)	24	76° 56' 3? – 10° 20' 55?	1,023	C, E, H
Korangumudi (KO)	35	76° 54' 45? – 10° 18' 50?	1,040	C, T, H
Puthutotam (PU)	50	76° 58' 2? – 10° 20' 28?	1,144	C, T, H
Andiparai (AN)	185	76° 59' 36? – 10° 23' 39?	1,295	T, H
Manamboli (MA)	200		813	C, D
Karian Shola (KS)	650	76° 50' 0? – 10° 28' 34?	807	D, B
Varagaliar (VA)	2,000	76° 51' 56? – 10° 25' 4?	681	D, B
Iyerpadi-Akkamalai (IYAK)	2,600		1,354	T, H, G

[a] Average of readings taken at sampling points as described in Methods.
[b] E – *Eucalyptus*, C – coffee, T – tea, R – reservoir, H – Human habitation, D – Moist and dry deciduous forests, B – Bamboo, G – Grassland.

Areas of fragments were obtained from Kumar *et al.* (1995) and Umapathy and Kumar (2000) and, in some cases, company records or direct on-field measurements of smaller fragments. Fragments had roads passing through or adjacent to them; Pannimade was the only fragment over 100 m away from any main road. One of the study sites (Varattuparai 1–3), considered as three separate fragments in the earlier publications, was considered as single fragment during this study. A small road and a border strip clearing separate the three portions of this fragment. All sorts of birds, including understorey and canopy species, were seen crossing these narrow openings and, from the perspective of birds, these sites were effectively parts of a single fragment. Similarly, Iyerpadi and Akkamalai, although cut by a road towards the northern periphery, are essentially one contiguous patch for the highly vagile birds, and are therefore considered as a single fragment (Iyerpadi-Akkamalai complex) for this study. As this was the largest patch in this altitudinal range, and being relatively undisturbed and lying within the Indira Gandhi Wildlife Sanctuary, it was also used as a 'control' site against which other fragments are compared in some analyses. This patch, however, did not range into elevations below 1,200 m and lacked many typical low-elevation bird species (see Chapter 4). I therefore sampled three fragments at lower elevations (spanning 650 m to 1,000 m), including a very large fragment (Varagaliar, 2,000 ha), a large fragment (Karian Shola, 650 ha), and a medium-sized fragment (Manamboli, 200 ha).

3.3 Bird surveys

The fixed-radius point count method was used to survey bird populations in each site. A radius of 50 m and duration of 5 min was used. Details of the method are presented elsewhere (Raman in press). No two points sampled on the same day were closer than 100 m to avoid overlap. Points sampled on different days unavoidably overlapped to some extent in the smaller fragments.

A total of 389 point count samples were obtained across the 13 fragments between January and May 2000, spanning the peak breeding season and the period when winter migrants are present in the study area. Bird surveys were designed upon two major needs, but were limited by two main constraints. The primary need was to sample all sites in a relatively uniform and efficient manner during the main breeding season. In addition, there was a need to distribute sampling effort in relation to fragment size. Valid comparisons can be made only if the sampling effort (number of point count surveys) at a site is proportional to the area of the site. This ideal sampling scheme was not possible due to two constraints. First, although all fragments were sampled using the same methods and over the same period of time, for logistic reasons, two of the lower-elevation fragments could be sampled mainly towards the end of the breeding season. The sampling in proportion to area criterion was also impossible to adhere to since, for every additional point count survey in a 1 ha fragment, 2,600 point count samples would be needed in the largest fragment sampled in this study (Iyerpadi-Akkamalai, 2,600 ha). Although, in general, more samples were taken in larger fragments, this was not exactly proportional to fragment area, and larger fragments tended to be sampled less intensively than smaller fragments. Besides this, detectability and visibility tended to be better in small and medium-sized fragments (except Pannimade). As a result of these two factors (disproportionate sampling and detectability), the species richness of large fragments may be underestimated and the results of the study can therefore be only considered as a conservative assessment of the effects of fragmentation.

One site was chosen in each of the three following types of plantations that were most common in the landscape matrix around rainforest fragments: tea, coffee, and *Eucalyptus*. In each of these three sites, 25 point count surveys were carried out. It was not possible to sample additional sites or choose sites to make specific comparisons between fragments surrounded by different kinds of matrix elements during this study.

3.4 Habitat sampling

In each of the 13 rainforest fragment and 3 plantation sites, a number of vegetation variables were measured in order to characterise habitat structure and floristic composition of the sites. Tree densities were estimated using the point-centred quarter method (PCQ, Krebs 1989). From 10 to 30 plots were measured depending on the size of the fragment (25 plots in plantations). In three of the smaller fragments that had very dense tangled undergrowth it was difficult to do PCQ plots and therefore trees within ten 5-m radius circles around the observer were counted to estimate density. In most cases,

trees were identified to species using available floras and field guides (Gamble 1935, Pascal and Ramesh 1997). A number of species were identified to genus level and given code numbers; the few trees that remained unidentified were pooled into a single category.

Other habitat variables were measured at 25 points in each fragment or plantation site distributed over areas where bird surveys were carried out. Altitude was measured using an altimeter (10 m accuracy). Other variables (percentage canopy cover, canopy height, vertical stratification, leaf litter depth, shrub and cane densities) were measured with standard methods (Raman *et al.* 1998). Care was taken to avoid locating sampling points in the centre of highly disturbed trails, most samples were taken at least 10 m into the forest interior. The latitude and longitude of each sampling site (to the nearest 0.5") was obtained using a hand-held global positioning system (Garmin GPS 12 XL). For large fragments, a reading was obtained close to the centre of the fragment or, in two cases of elongated fragments, readings were obtained at the two ends and averaged to obtain a location that fell close to the centre of the fragment.

3.5 Analysis

3.5.1 *Bird community parameters*

The 106 bird species recorded during the study were classified into rainforest and open-country (non-rainforest) birds. The rainforest species included birds that normally occurred even in mature undisturbed rainforests in the Anamalai hills and other rainforest areas in the Western Ghats (Ali and Ripley 1983, T. R. S. Raman unpublished data). In contrast, open-country species were birds that never occurred in mature, undisturbed tropical rainforest and occurred only in disturbed rainforest fragments or in naturally drier and open habitats. All analyses were performed using all species, using only rainforest species, and with only open-country species.

Bird species richness (average per point count sample and cumulative number of species recorded) in each site was a fundamental variable of interest. The average bird abundance per point was a second major parameter of interest. In each point count sample, many bird detections were made by calls and the number of individual birds could not be counted in the field. For each species, however, information on flock sizes (a flock representing 1 to many individuals for this purpose) was collected separately during surveys and opportunistic observations. For each aural detection of a species, the number of individuals in the flock was randomly selected using a Monte-Carlo procedure. More details on flock size data collection and use are given elsewhere (Raman in press). This procedure enabled the estimation of the number of individuals in each point count sample.

Cumulative species richness and abundance (individuals/ha) of birds belonging to eight different diet-guilds were also estimated using the point count survey data. Birds were classified as bark-surface feeders, carnivores, frugivores, nectarivore-insectivores, omnivores, and canopy, understorey, and terrestrial insectivores, using natural history information in Ali and Ripley (1983)

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and direct observations (T. R. S. Raman, unpublished data). The species-abundance data from each site was used to estimate similarities between sites in bird community composition using the Morisita index (Wolda 1981). Guild and similarity analyses were done separately for all, rainforest, and open-country species separately.

3.5.2 *Habitat variables*

Tree densities and basal areas were computed for each site using data from the PCQ or circular plots. For other variables measured at replicate points in each site (such as shrub density or canopy cover) the averages across points was calculated. Vertical stratification was measured as the average number of vertical strata with foliage at each point. As these measurements were taken at different points, the coefficient of variation of this index was used as a measure of horizontal heterogeneity (Raman *et al.* 1998). As several vegetation variables were intercorrelated, they were summarised using principal components analyses to extract a smaller set of uncorrelated components that described the vegetation gradient.

The latitude-longitude location data of each site were converted to X- and Y-coordinates (in metres) using 1" = 30.867 m as a conversion factor. The distance between any two sites as well as the distance from each site to the Iyerpadi-Akkamalai 'control' site was then estimated. This was used as a measure of isolation of fragments from the putative source area for some analyses.

3.5.3 *Relationships between birds, habitat, area, and isolation*

The influence and relative importance of area, isolation, altitude, and habitat (represented by the principal component scores) on bird community attributes was examined using stepwise multiple regression (Zar 1999). Stepwise regression analyses were also carried to examine the influence of these variables on the number of bird species in eight different diet-guilds and within different defined categories of birds such as migrants, endemic species, and priority species. Priority species were defined as birds of restricted-range (Stattersfield *et al.* 1998), discontinuous distribution (in rainforests of southwest India, Sri Lanka, and northeast India, Ali and Ripley 1983), or near-threatened (Collar *et al.* 1994) and did not include endemic species.

The expected species richness of each site was also derived under two random sample null models that modelled the effects of random colonisation (passive sampling) of sites by bird species. The two models used were:

(a) **Area-based passive sampling:** This is the model of Coleman *et al.* (1982), where an individual has a greater probability of colonising large rather than small fragments. Specifically, the probability of a bird occurring at a site was taken to be the proportional area of the site (p_{area} = area of site/total area summed across all sites). Thus, the probability that at least one individual of a species *i* occurs in

a site is given by $[1 - (1 - p_{area})^{ni}]$, where ni is the total number of individuals of species i recorded across all sites. The expected species richness is the summation of this probability across all species:

$$S_{area} = \sum_{i=1}^{S_p} [1 - (1 - p_{area})^{ni}]$$

Using the binomial distribution, the variance of S_{area} is given by (Coleman *et al.* 1982):

$$V_{area} = \sum_{i=1}^{S_p} (1 - p_{area})^{ni} - \sum_{i=1}^{S_p} (1 - p_{area})^{2ni}$$

(b) **Abundance-based passive sampling:** The Coleman *et al.* (1982) model was modified to predict the expected species richness under the situation where the actual number of individuals seen on an island was randomly sampled from the entire pool of individuals summed across all sites. The probability of colonisation was thus taken to be the proportion of individuals sampled in a given site (p_{abun} = number of individuals in a site/total number of individuals recorded across all sites). Following a similar derivation, the expected species richness under abundance-based passive sampling is:

$$S_{abun} = \sum_{i=1}^{S_p} [1 - (1 - p_{abun})^{ni}]$$

And the variance is given by:

$$V_{abun} = \sum_{i=1}^{S_p} (1 - p_{abun})^{ni} - \sum_{i=1}^{S_p} (1 - p_{abun})^{2ni}$$

3.5.4 *Species turnover and nested subset analyses*

Similarities between sites in bird community and tree species composition were measured using the Morisita index that is least sensitive to sample size effects (Wolda 1981). Dissimilarities were measured as $1 -$ Morisita index. Dissimilarity between sites in habitat structure was estimated as the Euclidean distance between sites in the PC1-PC2 ordination space. The altitudinal and geographic distances between sites were also calculated. The difference in the logarithms of the area of the sites was taken as a measure of dissimilarity in fragment size. The influence of dissimilarities between sites in area, location, habitat structure, and tree species composition, on the dissimilarities in bird community composition was assessed using stepwise multiple regression analyses.

The pattern of nested subsets or nestedness is defined by the condition that as one proceeds from sites containing the most to the fewest species, the species drop out, not at random, but in a specific progression such that each site is a subset of each preceding site (Patterson and Atmar 1986). Nested subsets structure of assemblages can reflect several different underlying processes such as differential colonisation, differential extinction, nested habitats, and passive sampling effects (see Worthen 1996, Wright *et al.* 1998 for reviews). Nestedness analyses are of great relevance for conservation for two main reasons. First, it would imply that community composition changes in a predictable manner and a set of small fragments would tend to contain more or less the same set of species, forming a subset of what is found in richer, larger fragments (Patterson 1987, Worthen 1996). Second, it helps identify patterns of differential extinction and species that are susceptible to extinction with decrease in fragment size or species richness.

It is not possible to address in detail in this chapter the different methods of nested subsets analyses. For the purpose of the present thesis, we use the analytical approach of Atmar and Patterson (1993) to determine nestedness. Starting with a presence-absence matrix of sites (rows) by species (columns), their nestedness calculator estimates an index of nestedness, called the matrix temperature, after maximally packing the matrix (presences cluster at the top left). The null distribution of matrix temperatures is calculated after similarly packing simulated matrices generated by distributing the observed number of presences at random in the matrix. Statistical significance was assessed using the tail probabilities of the simulated distribution (1,000 simulations).

4. RESULTS

In the 13 rainforest fragments, 4077 detections of birds were obtained, comprising of an estimated 7493 individuals in total (Appendix 4). Of the 106 bird species observed in this sample, 75 species (70.8%) were birds typical of rainforest (e.g., Great Hornbill, Malabar Trogon, Black-and-Orange Flycatcher). The remaining 31 species (29.2%) were typical of drier forests, forest edges, and degraded open areas of the Indian Peninsula, and included mostly common and widespread species (e.g., Common Tailorbird, Red-vented Bulbul, House Crow).

In addition, 449 detections comprising of an estimated 792 individual birds were made in tea, coffee, and *Eucalyptus* plantations. A total of 61 species was recorded in this sample, including 34 rainforest species (55.7%) and 27 open-country species (44.3%). While all 34 rainforest species were also detected in fragments, two of the open-country species (Pied Bushchat and Long-tailed Shrike) were not seen in rainforest fragments. Of the 47 bird species recorded in rainforest fragments but absent in the plantations, 41 (87.2%) were rainforest birds and 6 (12.8%) were open-country species.

4.1 Bird species richness and abundance in rainforest fragments

Bird species richness and abundance data were obtained from unequal sampling effort distributed across the 13 sites (Table 2). The number of point counts/ha, a measure of sampling intensity, ranged from 13−14 in the smallest fragments to less than 0.1 in the largest for reasons explained in the section on methods (section 3.3). In most cases, particularly in medium-sized fragments, the species richness appeared to have levelled off at near-saturation point reflecting adequate sampling effort. In the smallest fragments, few counts were carried out and 1 or 2 additional species were detected even in the last sample count, indicating that more species may be recorded. Field observation indicated that many of these detections were of birds that flew into the fragment from an adjacent site, perched for a few moments, and flew out again, and therefore using the site ephemerally. In the largest fragments also, a few additional species were being detected in the last few counts, and these appeared to be instrinsically rare and typical rainforest birds such as frogmouths, forest raptors, and owls.

Table 2: Sampling effort in the rainforest fragments in the Anamalai hills.

Fragment	Area (ha)	Relative area (%)	Number of point counts	Relative counts (%)	Sampling intensity (point counts/ha)
Kochank 1 (K1)	0.3	0.0052	4	1.03	13.33
Kochank 2 (K2)	0.5	0.0087	7	1.80	14.00
Varattuparai 4 (V4)	1	0.0174	6	1.54	6.00
Varattuparai 1−3 (V3)	7	0.1215	20	5.14	2.86
Pannimade (PA)	10	0.1735	30	7.71	3.00
Tata Finley (TF)	24	0.4165	30	7.71	1.25
Korangumudi (KO)	35	0.6073	30	7.71	0.86
Puthutotam (PU)	50	0.8676	30	7.71	0.60
Andiparai (AN)	185	3.2102	42	10.80	0.23
Manamboli (MA)	200	3.4705	45	11.57	0.23
Karian Shola (KS)	650	11.2792	40	10.28	0.06
Varagaliar (VA)	2,000	34.7054	30	7.71	0.02
Iyerpadi-Akkamalai (IYAK)	2,600	45.1170	75	19.28	0.03

4.1.1 *Trends in bird species richness, abundance, and population sizes*

Bird species richness changed from the smallest to the largest fragments in different ways depending on which set of species were considered. The total species richness increased from about 20−30 species in the small fragments (<10 ha) to over 50 species in the medium-sized fragments (30−50 ha), and then remained steady or declined slightly towards the largest fragments (Figure 1a). Open-country birds contributed substantially (up to about 40%) to the species richness of small and medium fragments. The number of open-country bird species declined with fragment size, being highest however in one highly disturbed medium-sized fragment, Korangumudi (Figure 1b). In contrast, the number of typical rainforest bird species increased with fragment size (Figure 1c). Even here, however, the species richness was lowest only below a threshold of 10 ha, and medium-sized fragments had nearly around 80% of the species that the largest fragments had (Figure 1c). It must

Figure 1: Total bird species richness (from cumulative list) of rainforest fragments in relation to area on a logarithmic scale. The results are presented separately for (a) all bird species (upper panel), (b) open-country bird species (middle panel), and (c) rainforest bird species (lower panel).

Sites:
K2 = Kochank 2
K1 = Kochank 1
V4 = Varattuparai 4
V3 = Varattuparai 1–3
PA = Pannimade
TF = Tata Finley
KO = Korangumudi
PU = Puthutotam
AN = Andiparai
MA = Manamboli
KS = Karian Shola
VA = Varagaliar
IYAK = Iyerpadi-Akkamalai

be noted that this discrepancy may have been higher if sampling intensity had been equal across sites. When the total number of resident bird species in fragments was considered, the patterns were nearly identical (Figure 2a–c).

The pattern of bird species richness recorded per point showed an interestingly different trend with fragment area. The average number of bird species per point did not change significantly or show any discernible trend with fragment size (Figure 3a). Again, however, the number of open-country species recorded per point was higher is small and medium-sized fragments, declining to negligible values in the largest fragments (Figure 3b). In contrast, the species richness per point of typical rainforest birds increased with fragment size, from smallest to the largest (Figure 3c). Notably however, the highest bird species richness per point was recorded in Pannimade, a small fragment with relatively well-preserved rainforest vegetation and low level of disturbance.

The pattern of change in bird abundance per point was also virtually identical to that shown by bird species richness per point, due to the obvious correlation between these variables (Figure 4a–c). Again, Pannimade had one of the highest values, with an average of 21 individual rainforest birds recorded in each point count.

These patterns are reinforced by regression and correlation analyses of the above data. Among a variety of models explored, two appeared to fit the data best—log-linear and log-polynomial models—the results of which are presented in Table 3. The log-polynomial models perform better (R^2 = 71−74%) than log-linear models (R^2 = 46−53%) in describing the pattern of total and resident bird species richness for all species combined. This inverse-U shaped relationship is because of the peak in species richness in medium-sized fragments. For open-country and rainforest bird species, the log-linear models perform nearly as well as the log-polynomial, indicating trajectories of decline and increase in species richness with area, respectively (Table 3, Figures 1, 2, 3, 4). The statistical significance of the relationships with fragment area is indicated by the Kendall rank-order correlation coefficients in Table 3.

Although a sizable number of rainforest bird species were recorded in small and medium-sized fragments, their population sizes (estimated as the product of individual densities and fragment area) were very small. None of the fragments less than 10 ha in area had any bird species represented by 5 or more pairs in the fragment (Table 4). Medium-sized fragments (10−100 ha) were better, as they contained populations of over 5 to over 25 pairs of more than two dozen rainforest bird species. Large populations of over 50 pairs of any rainforest bird species were, however, recorded only in the large fragments (>100 ha, Table 4). It must be noted that (i) most (>94%) species recorded in the smallest fragments (<1 ha) were transients with populations of less than 1 individual in the site, as it is virtually impossible for any species to be resident and entirely confined to such small areas, and (ii) many species (6−22%) were recorded as having population sizes of <1 individual even in medium and large-sized fragments (Table 4). The latter is partly due to sampling effects (see Discussion).
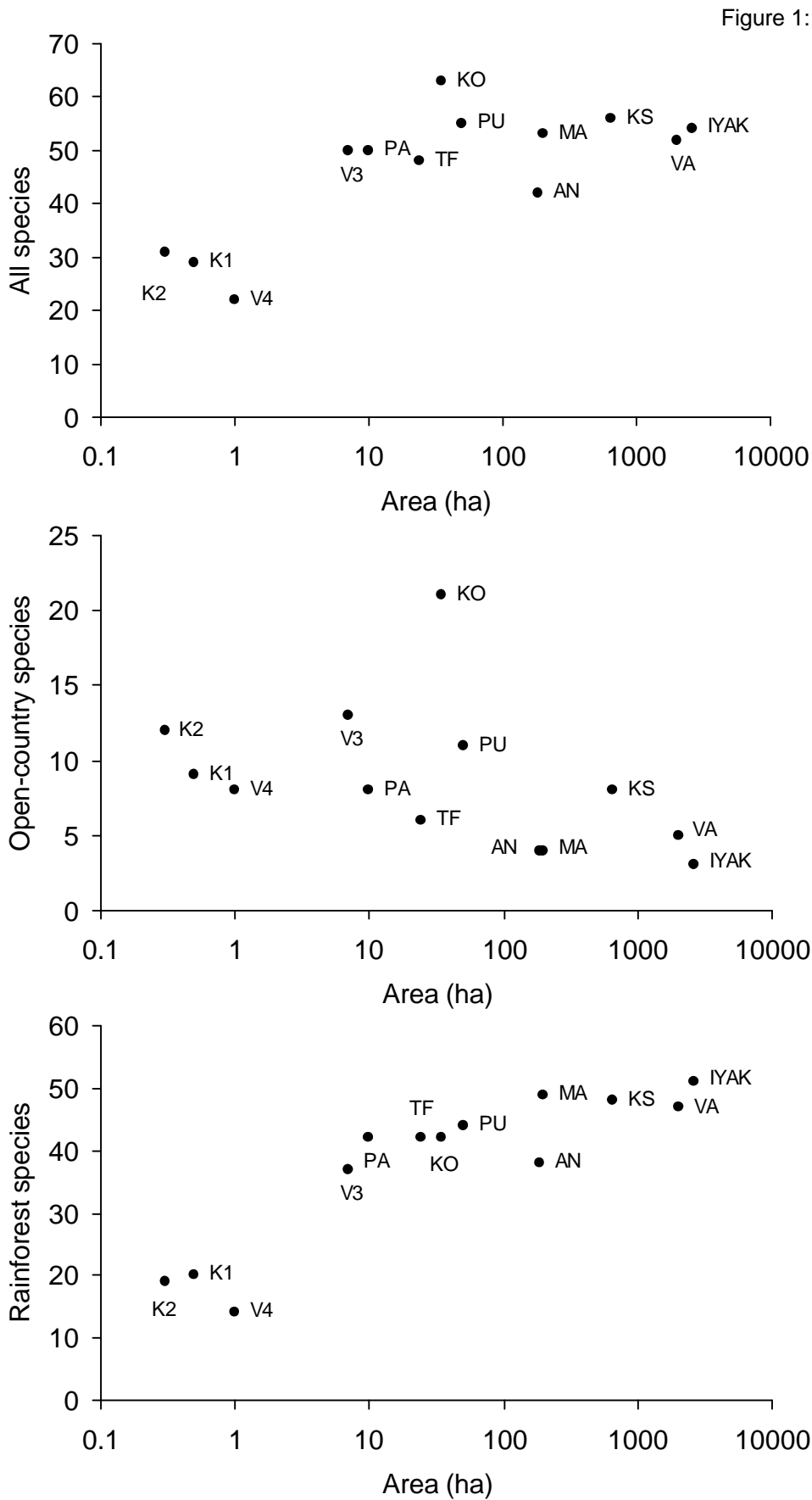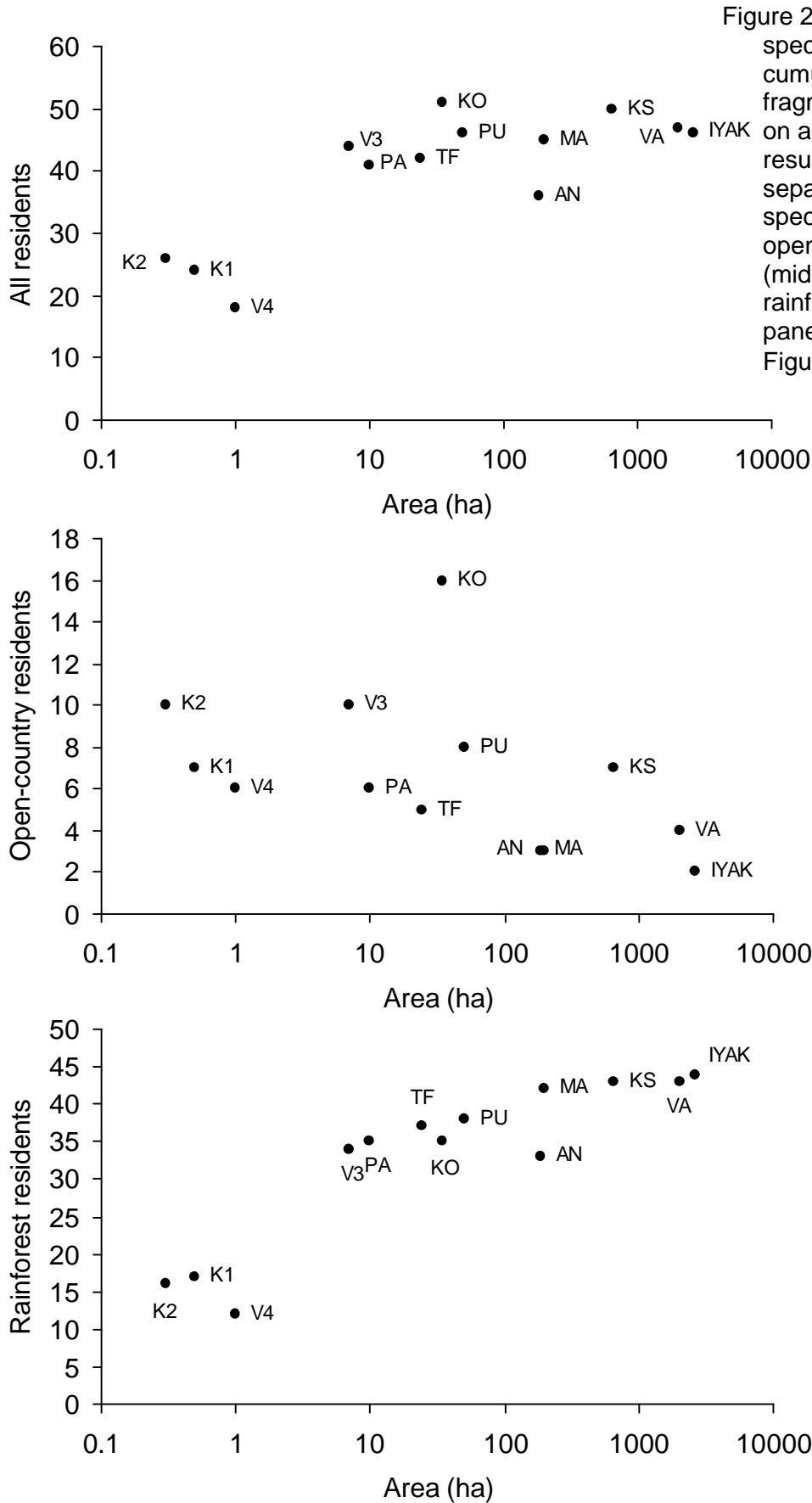
Figure 2: Total resident bird species richness (from cumulative list) of rainforest fragments in relation to area on a logarithmic scale. The results are presented separately for (a) all bird species (upper panel), (b) open-country bird species (middle panel), and (c) rainforest bird species (lower panel). Site names as in Figure 1.

Figure 3: Bird species richness per point count (mean ± SE) of rainforest fragments in relation to area on a logarithmic scale. The results are presented separately for (a) all bird species (upper panel), (b) open-country bird species (middle panel), and (c) rainforest bird species (lower panel). Site names as in Figure 1.
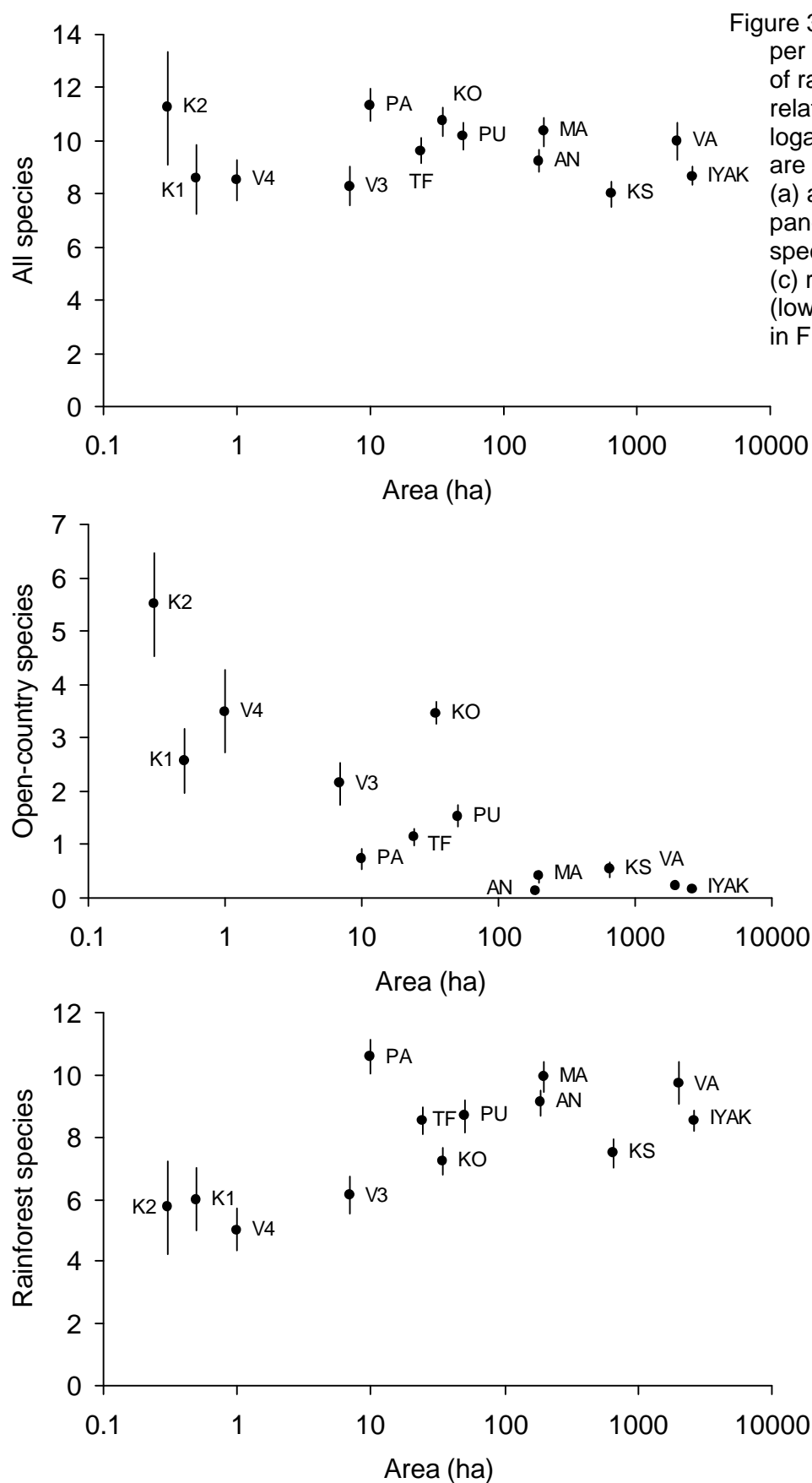
Figure 4: Bird abundance per point (mean ± SE) in the rainforest fragments in relation to area on a logarithmic scale. The results are presented separately for (a) all bird species (upper panel), (b) open-country bird species (middle panel), and (c) rainforest bird species (lower panel). Site names as in Figure 1.

All species (upper panel) — All species (individuals/point) vs Area (ha)
K2, K1, V4, PA, TF, KO, V3, PU, AN, MA, VA, KS, IYAK

Open-country species (middle panel) — Open-country species (individuals/point) vs Area (ha)
K2, K1, V4, V3, KO, TF, PU, PA, AN, MA, KS, VA, IYAK

Rainforest species (lower panel) — Rainforest species (Individuals/point) vs Area (ha)
PA, AN, MA, IYAK, TF, PU, VA, KO, K2, K1, V4, V3, KS

Table 3: Regression models and non-parametric Kendall correlations of data relating bird species richness and abundance estimates (y) to the logarithm of the area [x = log (area)] of fragments in the Anamalai hills.

Parameter	Linear[a] ($y = bx + c$)			Polynomial[a] ($y = ax^2 + bx + c$)				Kendall correlation
	b	c	R² (%)	a	b	c	R² (%)	τ
Total bird species richness								
All species	7.25	34.67	45.9	-5.45	26.05	24.42	71.0	0.45*
Open-country species	-1.997	11.89	21.5	-1.17	2.05	9.79	28.6	−0.50*
Rainforest species	9.24	22.78	72.2	-4.27	23.998	15.13	87.2	0.75**
Resident bird species richness								
All species	6.80	28.55	53.1	-4.32	21.73	20.81	73.8	0.50*
Open-country species	-1.56	9.26	22.1	-0.82	1.24	7.80	27.9	−0.47*
Rainforest species	8.37	19.28	74.9	-3.51	20.48	13.00	87.6	0.78**
Bird species richness/point								
All species	-0.15	9.84	2.2	-0.26	0.75	9.38	8.7	−0.13
Open-country species	-1.15	3.58	61.2	0.35	-2.37	4.21	66.8	−0.67**
Rainforest species	0.998	6.26	40.3	-0.61	3.11	5.17	54.9	0.49*
Bird abundance/point								
All species	-0.16	19.43	0.4	-0.35	1.03	18.81	2.26	−0.08
Open-country species	-2.19	6.89	54.1	0.48	-3.85	7.75	56.6	−0.62**
Rainforest species	2.03	12.55	38.1	-0.83	4.89	11.06	44.2	0.43*

[a]—Models log-linear and log-polynomial in relation to area of the fragment because x = log(area).
*—$P < 0.05$, **—$P < 0.01$, ***—$P < 0.001$ (N = 13 fragments)

Table 4: Population sizes of rainforest bird species in fragments in the Anamalai hills.

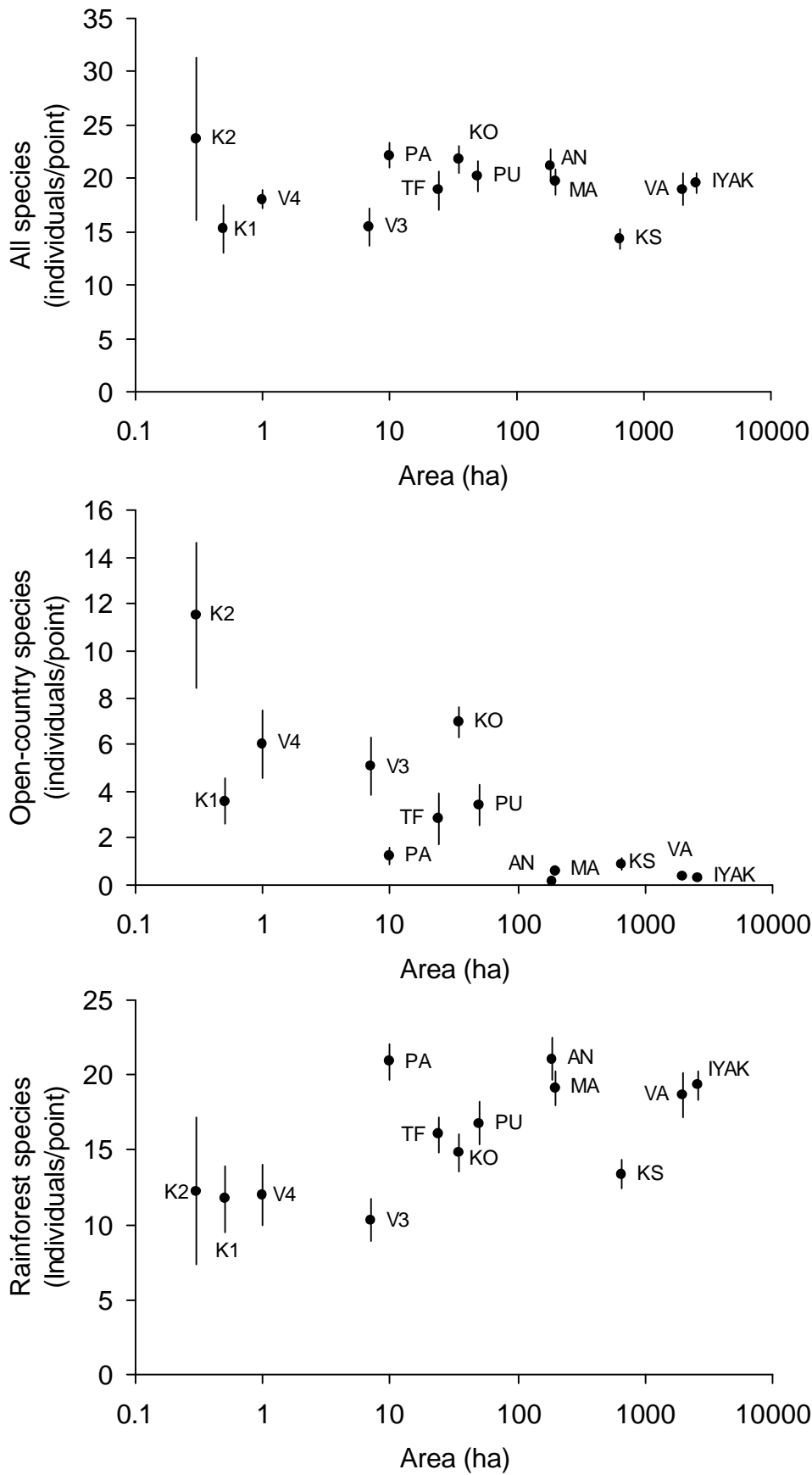| Population size[a]	Number of species in fragment[b]												
	K2	K1	V4	V3	PA	TF	KO	PU	AN	MA	KS	VA	IYAK
At least 1 bird	1	1	7	24	39	42	42	44	38	49	48	47	51
At least 2 birds	–	–	2	15	31	40	38	44	38	49	48	47	51
At least 5 birds	–	–	–	6	14	27	29	32	38	49	48	47	51
At least 10 birds	–	–	–	–	8	17	21	24	36	45	48	47	51
At least 25 birds	–	–	–	–	1	5	9	16	27	37	39	47	51
At least 50 birds	–	–	–	–	–	1	1	9	21	31	32	47	46
At least 100 birds	–	–	–	–	–	–	1	–	13	18	30	42	43
At least 500 birds	–	–	–	–	–	–	–	–	2	1	5	28	26
At least 1000 birds	–	–	–	–	–	–	–	–	1	–	1	17	18
	Percentage of species in fragment												
At least 1 bird	5.3	3.4	31.8	48.0	78.0	87.5	66.7	80.0	90.5	92.5	85.7	90.4	94.4
At least 2 birds	–	–	9.1	30.0	62.0	83.3	60.3	80.0	90.5	92.5	85.7	90.4	94.4
At least 5 birds	–	–	–	12.0	28.0	56.3	46.0	58.2	90.5	92.5	85.7	90.4	94.4
At least 10 birds	–	–	–	–	16.0	35.4	33.3	43.6	85.7	84.9	85.7	90.4	94.4
At least 25 birds	–	–	–	–	2.0	10.4	14.3	29.1	64.3	69.8	69.6	90.4	94.4
At least 50 birds	–	–	–	–	–	2.1	1.6	16.4	50.0	58.5	57.1	90.4	85.2
At least 100 birds	–	–	–	–	–	–	1.6	–	31.0	34.0	53.6	80.8	79.6
At least 500 birds	–	–	–	–	–	–	–	–	4.8	1.9	8.9	53.8	48.1
At least 1000 birds	–	–	–	–	–	–	–	–	2.4	0.0	1.8	32.7	33.3
Rainforest BSR[c]	19	29	22	50	50	48	63	55	42	53	56	52	54

[a]—Number of individual birds (estimated as density x fragment area)
[b]—Fragment codes as in Table 1
[c]—Number of rainforest bird species recorded in fragment

4.1.2 *Can bird species richness patterns be explained by passive sampling?*

The hypothesis that bird species richness in fragments was a result of passive sampling in relation to fragment area was not supported by the analysis (Figure 5a–c). Under this model, the large fragments were expected to have more species than observed, whereas the smaller fragments were expected to have fewer species than observed. The pattern was consistent irrespective of whether the analysis included all, open-country, or rainforest species. None of the fragments had observed species richness values falling within the 95% confidence interval of the expected species richness under the area-based passive sampling model (Figure 5a–c).
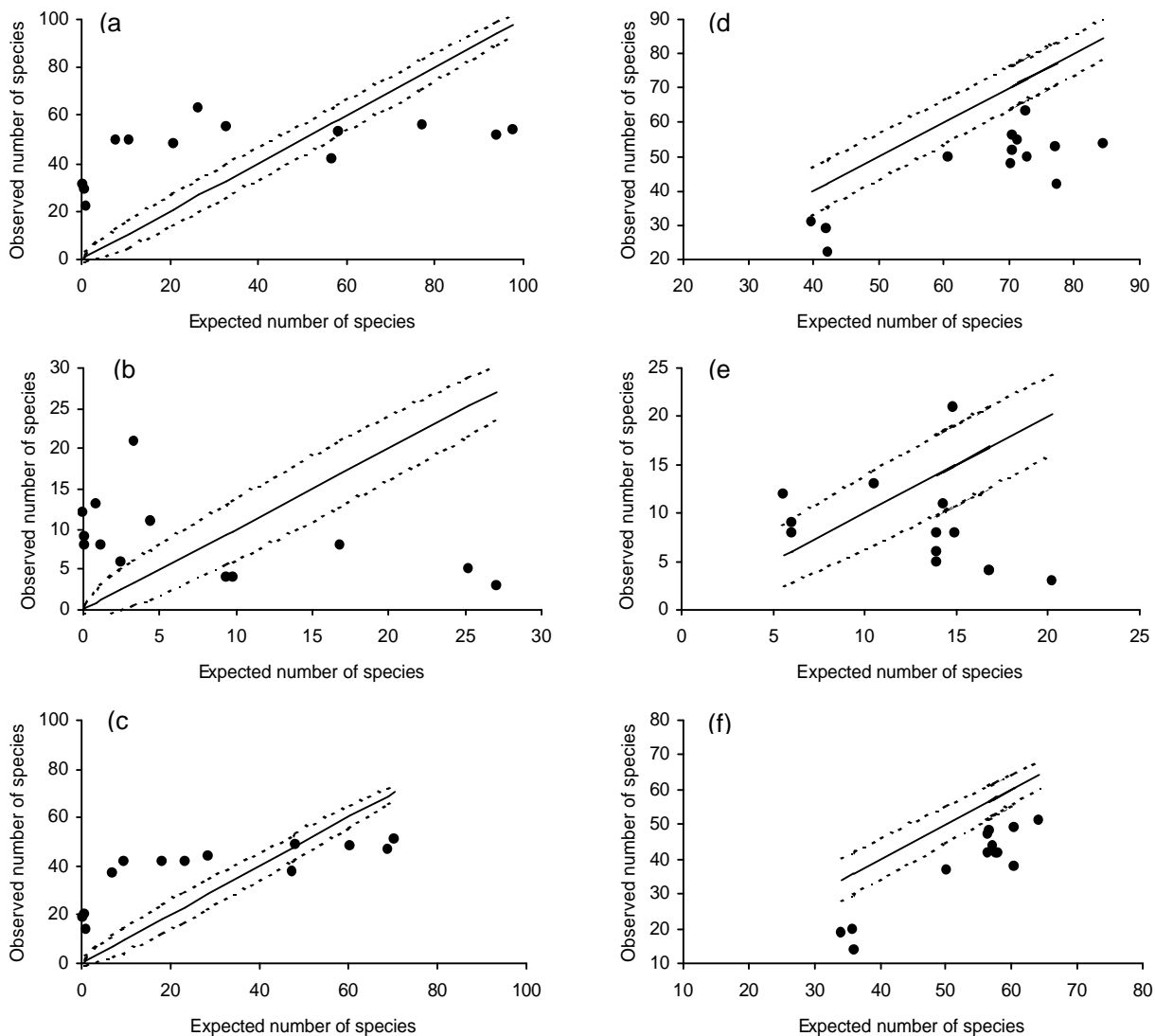
Figure 5: Expected bird species richness from passive sampling models in relation to observed bird species richness in rainforest fragments in the Anamalai hills. The panels on the left indicate area-based passive sampling for (a, upper left) all species, (b, mid left) open-country species, and (c, lower left) rainforest species. The panels on the right indicare results from abundance-based passive sampling models for (d, upper right) all species, (e, mid right) open-country species, and (f, lower right) rainforest species.

The abundance-based passive sampling also did not generally predict the bird species richness, but gave some illuminating insights. When all species were considered, the number of bird species expected in each site was generally higher than actually observed (Figure 5d). The discrepancy was highest for the largest fragments, with smaller fragments (that had fewer species) having only slightly less than expected. In contrast, when open-country bird species are examined, the larger fragments had far fewer species than expected whereas some small and medium-sized fragments had species richness values falling within the expected interval (Figure 5e). Notably, the highly disturbed rainforest fragment, Korangumudi, had the highest number (21) of open-country bird species. The analysis of rainforest bird species alone revealed a pattern (Figure 5f) similar to that of all species (Figure 5d). The three smallest fragments seemed to have, however, disproportionally (44 − 61%) fewer rainforest species than expected, in comparison to the three largest fragments (15 − 21% fewer species than expected, Figure 5f).

4.1.3 *Changes in vegetation and habitat structure*

As a prelude to analysing the effects of habitat structure, area, and isolation on bird community attributes, changes in vegetation across fragments were analysed and summarised using principal components analysis. There were pronounced differences between fragments in their vegetation attributes. Tree density, for instance, varied nearly four-fold from a low of 196 trees/ha in Korangumudi to a high of 755 trees/ha in Karian Shola (Table 5). Although basal area varied in a similar manner across sites, these variables did not show a clear trend in relation to fragment area. Nevertheless, although some small and disturbed fragments had high tree densities and basal areas like large fragments, this was to a significant extent contributed by pioneer trees such as *Macaranga indica* and exotic species such as *Maesopsis emeni*. Other parameters such as average canopy cover, canopy height, vertical stratification, and shrub density, were lower in disturbed small fragments and one medium-sized fragment (Korangumudi), than in less-disturbed small, medium- and large-sized fragments. Horizontal heterogeneity showed an opposite trend (Table 5).

Principal components analysis selected and combined correlated vegetation variables and identified two uncorrelated factors that summarised the trends of change in vegetation, explaining 71% of the total variation. The first factor (PC1) explained 44% of the variation in the data, and the second (PC2) explained a further 27%. PC1 was positively correlated to canopy cover, canopy height, vertical stratification, and shrub density, and negatively with horizontal heterogeneity (Table 6). PC2 was positively correlated to tree density, basal area, and leaf litter depth (Table 6). The PC1 site scores can be taken to represent their habitat structure (vertical and horizontal), while the PC2 scores index their woody biomass. The ordination of sites in PC1-PC2 space indicates the major trends of change in habitat structure and woody biomass across sites (Figure 6). The (euclidean) distance between any two sites in this ordination is a measure of their difference in vegetation characteristics.

Table 5: Changes in vegetation attributes across the rainforest fragments in the Anamalai hills.

Para-meter[a]	Fragment[b]												
	K2	K1	V4	V3	PA	TF	K0	PU	AN	MA	KS	VA	IYAK
CCOV	86.5	79.6	78.1	96.3	92.5	96.3	68.2	89.0	96.2	95.0	98.2	94.7	97.7
	(4.19)	(3.75)	(2.6)	(0.87)	(0.79)	(1.24)	(3.17)	(1.26)	(0.65)	(1.44)	(0.16)	(0.72)	(0.54)
CHT	17.8	19.3	17.8	17.4	22.4	31.3	20.7	22.7	22.7	24.5	27.0	28.6	22.7
	(0.95)	(1.57)	(2.19)	(2.22)	(1.75)	(1.93)	(2.09)	(1.87)	(1.83)	(1.11)	(0.72)	(1.41)	(1.39)
SDEN	6.6	10.0	6.7	12.8	34.2	11.0	11.5	7.9	26.3	11.6	23.8	15.8	10.2
	(0.72)	(1.02)	(0.58)	(0.75)	(2.97)	(0.92)	(2.89)	(0.78)	(3.00)	(1.08)	(2.42)	(1.67)	(0.64)
VSTR	4.3	3.7	4.3	4.64	5.6	5.32	3.36	5.12	4.84	5.08	5.12	5.44	4.97
	(0.42)	(0.33)	(0.39)	(0.27)	(0.24)	(0.24)	(0.19)	(0.21)	(0.24)	(0.29)	(0.25)	(0.21)	(0.28)
HHET	9.84	9.05	9.2	5.82	4.37	4.44	5.67	4.12	4.87	5.67	4.83	3.84	5.59
TDEN	424	382	484	295	534	331	196	239	431	582	755	446	697
	(40.3)	(12.0)	(39.4)	(7.6)	(13.7)	(5.6)	(1.9)	(2.4)	(4.4)	(5.8)	(7.6)	-	(5.00)
BASA	141.2	62.9	50.7	33.5	47.5	40.3	31.3	52.5	84.5	114.4	95.9	36.3	74.4
LITT	5.2	5.2	3.1	4.0	4.3	4.8	2.9	3.6	5.1	6.6	3.7	3.6	6.9
	(0.79)	(0.35)	(0.34)	(0.21)	(1.29)	(0.45)	(0.24)	(0.39)	(0.50)	(0.61)	(0.30)	(0.30)	(0.45)

[a]—CCOV = canopy cover (%), CHT = canopy height (m), SDEN = shrub density (number of shrubs/plot), VSTR = vertical stratification (number of vertical strata), HHET = horizontal heterogeneity (%CV of VSTR), TDEN = tree density (trees/ha), BASA = basal area (m²/ha), LITT = leaf litter depth (cm).
[b]—Fragment codes as in Table 6.1

Table 6: Results of principal components analysis of vegetation variables showing eigenvalues and Pearson's correlations between original variables and extracted components.

Component	PC1	PC2
Eigenvalue	3.523	2.158
Variation explained (%)	44.0	27.0
Cumulative %	44.0	71.0
Pearson' correlations (*df* = 11)		
Canopy cover	0.79***	0.44
Canopy height	0.79***	–0.06
Shrub density	0.63*	–0.02
Vertical stratification	0.90***	0.18
Horizontal heterogeneity	–0.87***	0.33
Tree density	0.38	0.72*
Basal area	–0.16	0.87**
Leaf litter depth	0.11	0.81**

*—$P < 0.05$, **—$P < 0.01$, ***—$P < 0.001$ (*df* = 11)
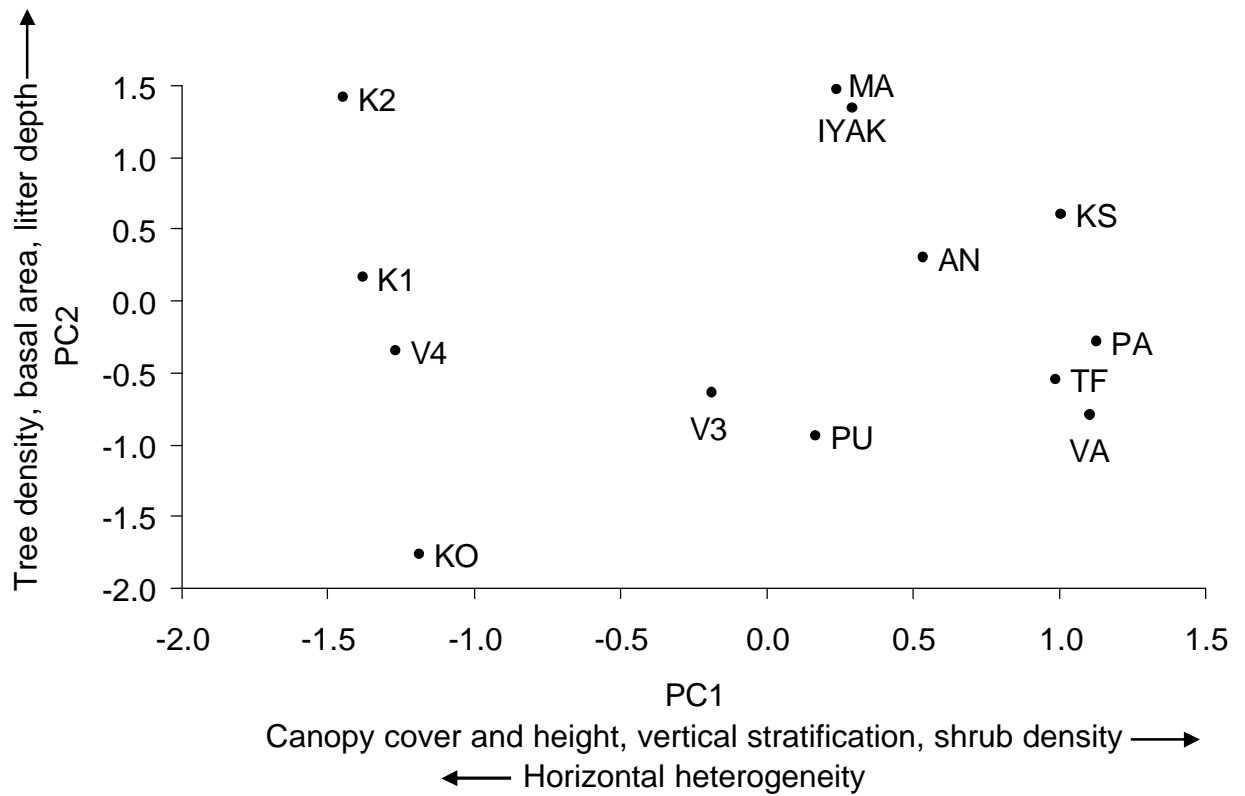
Figure 6: Ordination of rainforest fragments in the Anamalai hills using principal components analysis of vegetation variables.

4.1.4 *Influence of area, isolation, habitat structure, and altitude*

The influence of fragment area and isolation, on bird species richness and abundance was assessed through stepwise multiple regression analyses. Isolation was measured as the distance of each site from the largest 'control' fragment (IYAK), which itself was considered to be non-isolated (isolation = 0 km). Habitat structure was indexed by the PC1 and PC2 scores of the fragments. Table 7 indicates significant predictor variables, excluding altitude, which although included in the analyses was not found to be a significant predictor of any of the bird community variables.

The variables influencing total and resident bird species richness were similar. Bird species richness (all species) increased significantly with fragment area. In addition, it tended to decline with increasing PC2 scores (woody biomass), although this was of not statistically significant ($P \leq 0.15$, Table 7). The species richness of open-country birds was unrelated to fragment area. Instead, it was strongly negatively influenced by both PC1 (habitat structural development) and PC2, and showed a tendency to be positively related to isolation from the largest fragment. In contrast, rainforest bird species richness, increased significantly with fragment area, and tended to also increase with the structural development of rainforest vegetation (PC1, Table 7).

The predictor variables influenced point richness and abundance somewhat differently. The richness and abundance with all species included was not significantly related to any variable, as may

be expected, because, these parameters were nearly constant across sites (Figures 3a, 4a). The point richness and abundance of open-country birds decreased significantly with forest structural development (PC1) and also tended to decrease with fragment area. In contrast, point richness and abundance of rainforest birds was strongly related positively only to rainforest structural development (PC1, Table 7). Thus, although fragment area more strongly influenced fragment-level richness of rainforest birds, the structural development of rainforest vegetation had greater influence on point richness and abundance of rainforest birds. The abundance of rainforest birds also showed a tendency to be higher in fragments that were closer to the Iyerpadi-Akkamalai 'control' site (Table 7).

Table 7: Results of stepwise multiple regression of bird species richness and abundance measures on area, altitude, and habitat structure of fragments in the Anamalai hills.

Dependent variable	Beta (standardized regression coefficient)					Regression ANOVA		
	LogArea	PC1	PC2	Isolation	R^2	F	df	P
Total species richness								
All	0.727**	–	–0.360[+]	–	0.586	7.09	2,10	0.0121
Open-country	–	–0.688*	–0.549*	0.580[+]	0.731	5.45	4,8	0.0204
Rainforest	0.603*	0.360[+]	–	–	0.791	18.94	2,10	0.0058
Resident species richness								
All	0.775**	–	–0.336[+]	–	0.642	8.96	2,10	0.0059
Open-country	–	–0.706*	–0.504*	0.655[+]	0.714	5.00	4,8	0.0256
Rainforest	0.605**	0.380[+]	–	–	0.825	23.62	2,10	0.0002
Species richness/point								
All	–	–	–	–	–	–	–	–
Open-country	–0.357[+]	–0.621**	–	–	0.817	22.38	2,10	0.0002
Rainforest	–	0.806***	–	–	0.650	20.41	1,11	0.0009
Abundance/point								
All	–	–	–	–	–	–	–	–
Open-country	–0.364[+]	–0.542*	–	–	0.697	11.51	2,10	0.0026
Rainforest	–	0.784**	–	–0.361[+]	0.543	5.95	2,10	0.0198

Altitude of fragments was included as a variable in the analyses but is not listed above as only significant results are presented; [+]—$P \leq 0.15$, *—$P \leq 0.05$, **—$P \leq 0.01$, ***—$P \leq 0.001$.

4.2 Changes in bird species composition

4.2.1 *Patterns of species turnover*

The similarity in bird species composition between sites was calculated with the Morisita index using the data on bird densities in each fragment. The matrix of similarities was used as input for nonmetric multidimensional scaling which converged on a two-dimensional configuration (stress = 0.073). Ordination of fragments on these two dimensions (Figure 7) graphically represents the relative
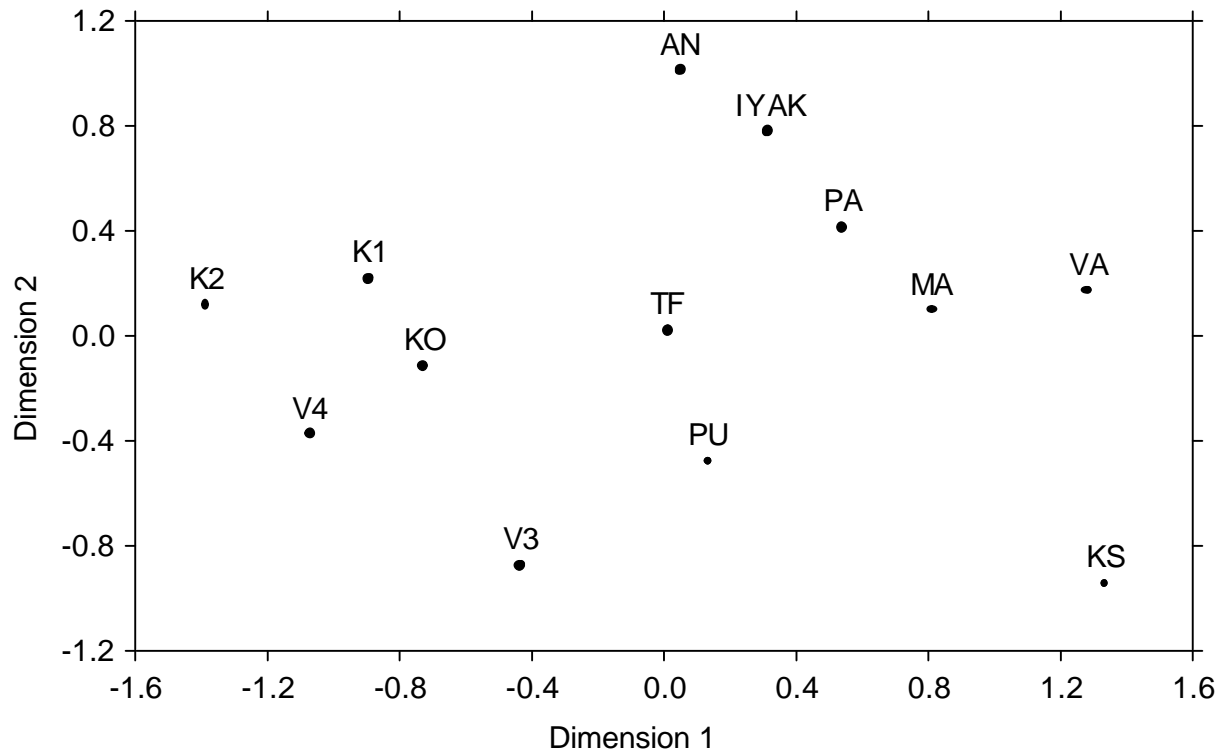
Figure 7: Similarity in bird community composition among rainforest fragments in the Anamalai hills illsutrated using multidimensional scaling ordination.

similarities between sites—the greater the distance between any two sites in the figure, the more different their bird community composition.

The ordination shows that three of the smallest fragments (K2, K1, V4) and one highly disturbed medium-sized fragment (KO) are similar in bird species composition as indicated by their proximity (Figure 7). All the large fragments (IYAK, VA, MA, AN), and one of the relatively undisturbed small fragments (PA), form another group towards the top right, with three medium-sized fragments (PU, TF, V3) occupying intermediate positions. One of the large fragments (KS) appeared to be relatively dissimilar from all other fragments in the bird community composition.

The similarity in bird community composition of sites with the control site (IYAK) was not significantly related to the fragment area ($\tau = 0.212$, $N = 12$, $P = 0.337$; Figure 8a). The analysis was repeated excluding three low-elevation sites, which tended to differ in bird community composition (open circles in Figure 8a). Bird community similarity with the control site showed a stronger positive trend indicating that larger fragments tended to be more similar to the control site, but this was not statistically significant ($\tau = 0.444$, $N = 9$, $P = 0.095$). This weak relationship was due to the wide variation in intermediate-sized fragments. Particularly notable was the large difference between the highly disturbed site V3 and relatively undisturbed site PA, in their bird community similarity with IYAK despite being only 3 ha different in area (Figure 8a). After the large fragment Andiparai (AN), Pannimade (PA) was the most similar site in bird community composition to the control site.
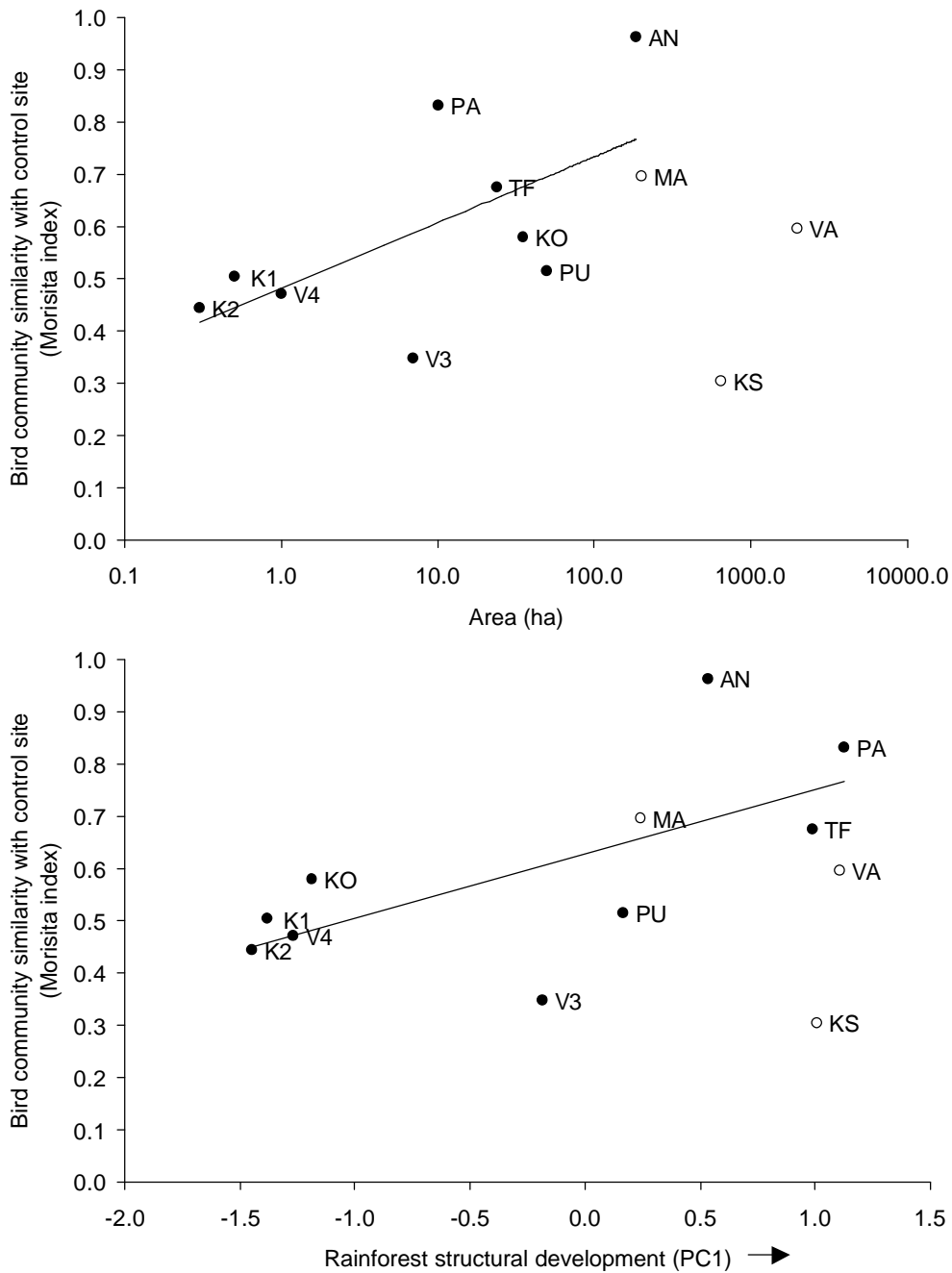
Figure 8: Similarity of rainforest fragments with the control site (Iyerpadi-Akkamalai) in bird community composition in relation to fragment area (a, upper panel) and rainforest habitat structure indexed by PC1 (b, lower panel). Lower elevation sites are indicated by open circles.

Besides area, the influence of isolation, PC1, PC2, and altitude on the similarity in species composition with IYAK were examined using Kendall correlations. Only forest structural development (PC1) showed a positive correlation (all sites: $\tau = 0.364$, $P = 0.0998$; exluding low-elevation sites: $\tau = 0.556$, $P = 0.0371$; Figure 8b). Thus, similarity in habitat structure with the control site appeared to exert a stronger influence on the similarity in bird community composition.

4.2.2 *Influence of site and habitat attributes on species composition and turnover*

Sites may be expected to be less similar in bird species composition if they were geographically or altitudinally distant, or if they were dissimilar in habitat structure or tree species composition. This was examined in two ways using stepwise multiple regression models. First, the similarity of each of the 12 fragments with the control (IYAK) fragment was related to their corresponding physical distances or dissimilarities in habitat with IYAK. Second, a similar approach was used with the data from the matrix of similarities between all possible pairs of sites ($N = 78$ pairs). In both cases, the analyses were carried out separately for bird community similarities calculated with the sets of (a) all species, (b) open-country species, and (c) rainforest species (Table 8).

Similarity of fragments with the control site in bird community composition (all species or only rainforest species) was related to two main factors—tree species composition and area. Fragments that were more dissimilar in tree species composition or were more different in area had less similar bird community composition, with the effects of variation in tree species composition being stronger than the effects of area (Table 8). In contrast, the similarity in community composition considering open-country species alone was negatively related to altitudinal distance and positively to geographic distance from the control site (Table 8).

Table 8: Results of stepwise multiple regression exploring the effects of differences between fragments in location and habitat attributes on their similarity in bird community composition in the Anamalai hills.

	Beta (standardized regression coefficient)					Regression ANOVA			
	AREA DIFF	TREE DISM	STRU DISM	GEOG DIST	ALTI DIST	R^2	F	df	P
Similarity with control site (IYAK)									
Species set									
All	−0.803*	−0.908*	0.336	–	−0.293	0.755	5.40	4, 7	0.0264
Open-country	–	–	0.202	0.671*	−1.262**	0.773	9.10	3, 8	0.0059
Rainforest	−0.685*	−0.936*	0.477[+]	–	−0.327	0.753	5.34	4, 7	0.0271
Similarity between sites (all possible pairs)									
Species set									
All	−0.256**	−0.263*	−0.247*	−0.251*	–	0.438	14.25	4, 73	< 0.0001
Open-country	–	−0.212[+]	−0.248*	0.382*	−0.534***	0.269	6.73	4, 73	< 0.0001
Rainforest	−0.182[+]	−0.281*	−0.162[+]	−0.276*	–	0.382	11.26	4, 73	< 0.0001

Indices of distance/dissimilarity between fragments:
    AREA DIFF—difference in the logarithms of the area of the fragments
    TREE DISM—dissimilarity in tree species composition (1−Morisita index)
    STRU DISM—structural dissimilarity (Euclidean distance using PC scores)
    GEOG DIST—geographic distance between sites (km)
    ALTI DIST—difference in average altitudes of the sites (m)
Significant coefficients are marked: [+]—$P \leq 0.15$, *—$P \leq 0.05$, **—$P \leq 0.01$, ***—$P \leq 0.001$.

These results were reinforced by the analysis using data on all possible pairs, but in addition, other variables were also found to be influential. Bird community similarity (all species and rainforest species only) was negatively related to structural dissimilarity and geographic distance, in addition to difference in area and dissimilarity in tree species composition as in the first analysis. The bird community composition considering only open-country species was found to be negatively related to structural dissimilarity between sites, besides the relationships with physical distance measures described above (Table 8). It must be noted, however, that this analysis was done with 78 cases (measures of similarity/distance) for each variable, derived by all possible pairs comparisons of only 13 sites. The resultant P-values of statistical significance must be treated with caution. The low R^2 ($<$ 0.44) also indicates that considerable variation remained unexplained even after accounting for the effects of these multiple factors.

4.2.3 *Nested subsets analyses*

Nested subsets structure of community composition, analysed with the program NESTCALC, showed distinct patterns for each species set analysed. For all three species sets (all, open-country, or rainforest birds) the bird community was found to be highly significantly nested (Table 9). The nestedness is assessed here, however, by arranging sites in the order of maximal matrix packing—which mostly corresponds to what would be obtained by ordering the sites on the basis of bird species richness. Depending on the species set considered, the rank ordering of sites varies and is also different from the rank-ordering based on fragment area (Table 9). For instance, although Andiparai

Table 9: Rank-order of rainforest fragments in the Anamalai hills on the basis of area and following nested subset analysis for each species set.

Rank	Fragment area	Species set (species richness)		
		All	Open-country	Rainforest
1.	IYAK	KO (63)	KO (21)	IYAK (51)
2.	VA	KS (56)	V3 (13)	MA (49)
3.	KS	PU (55)	K2 (12)	KS (48)
4.	MA	IYAK (54)	PU (11)	VA (47)
5.	AN	VA (52)	K1 (9)	PU (44)
6.	PU	TF (48)	KS (8)	TF (42)
7.	KO	PA (50)	PA (8)	PA (42)
8.	TF	MA (53)	V4 (8)	KO (42)
9.	PA	V3 (50)	VA (5)	V3 (37)
10.	V3	AN (42)	TF (6)	AN (38)
11.	V4	K2 (31)	MA (4)	K1 (21)
12.	K1	K1 (29)	AN (4)	K2 (19)
13.	K2	V4 (22)	IYAK (3)	V4 (14)
	Nestedness statistics			
	Matrix fill (%)	42.2	27.7	49.2
	Matrix temperature ($T°$)			
	Observed	32.05	14.03	24.61
	Expected (SD)	64.55 (3.01)	53.15 (6.08)	63.05
	P(T<observed)	5.64×10^{-27}	6.80×10^{-11}	6.64×10^{-32}

Fragment codes as in Table 1.

(AN) is ranked 5 according to area, it ranks 10 in the gradient of nestedness of rainforest bird species. In contrast, the small fragment Pannimade (PA) ranked 9 on area, climbs to greater importance at rank 7 when rainforest bird species richness and nestedness are considered.

The pattern of nestedness across fragments is illustrated in Figure 9. The filled cells indicate occurrences, the empty ones absences. The line is an estimate of an extinction threshold and populations (cells) below the line or close to it may be expected to be the first to disappear if species richness (or area) of the fragment declines further. Despite the nestedness being highly significant, it is clear that there is considerable scatter about the line and many species occur idiosyncratically in sites where they are not expected under the condition of perfect nestedness. Similarly there are idiosyncratic sites showing unexpected presences or absences of species (Figure 9). The nestedness is thus far from perfect and other factors may be at work.

4.3 Plantations and landscape matrix effects

4.3.1 *Species richness and composition in plantations*

The data from the tea, coffee, and *Eucalyptus* plantations (25 point counts in each) were compared with an equal sample of 25 point counts selected at random from the samples taken in the rainforest control site at a similar elevation (Iyerpadi portion). A total of 78 bird species were recorded in the plantations. Of these, 38 bird species were seen only in one of the plantation types (mostly in coffee) and were not recorded in the rainforest sample. This included 14 rainforest bird species and 24 open-country species. These 14 rainforest bird species included 8 species typically found in rainforests at lower elevations than Iyerpadi (below 1,100 m), 5 species seen infrequently in rainforest interior and more along edges on other occasions (Grey Junglefowl, Grey Wagtail, Eurasian Blackbird, Rufous Babbler, Emerald Dove), and one vagrant represented by a single detection in *Eucalyptus* plantation (Ashy Drongo). Seventeen bird species were seen only in the rainforest site and were not recorded from plantations. All 17 species were rainforest birds and included species such as the Dark-fronted Babbler, Malabar Trogon, Great Hornbill, Greater Flameback, Brown-cheeked Fulvetta, Yellow-browed Bulbul, and all three endemic flycatchers: Black-and-Orange Flycatcher, Nilgiri Flycatcher, and White-bellied Blue Flycatcher.

The total number of bird species recorded in tea, *Eucalyptus*, and coffee plantations and in rainforest were: 26, 41, 50, and 40, respectively. The corresponding number of rainforest bird species recorded across these four strata were: 10, 21, 30, and 37, respectively. The tea plantation was clearly the worst habitat for rainforest birds, whereas the coffee plantation had only slightly lower bird species richness than rainforests (Figure 10).

These patterns were also clear in the analyses of point richness and abundance data. Bird species richness per point count was highly significantly different across the four strata, irrespective of species set considered—all, open-country, or rainforest birds (Kruskal-Wallis analysis of variance,
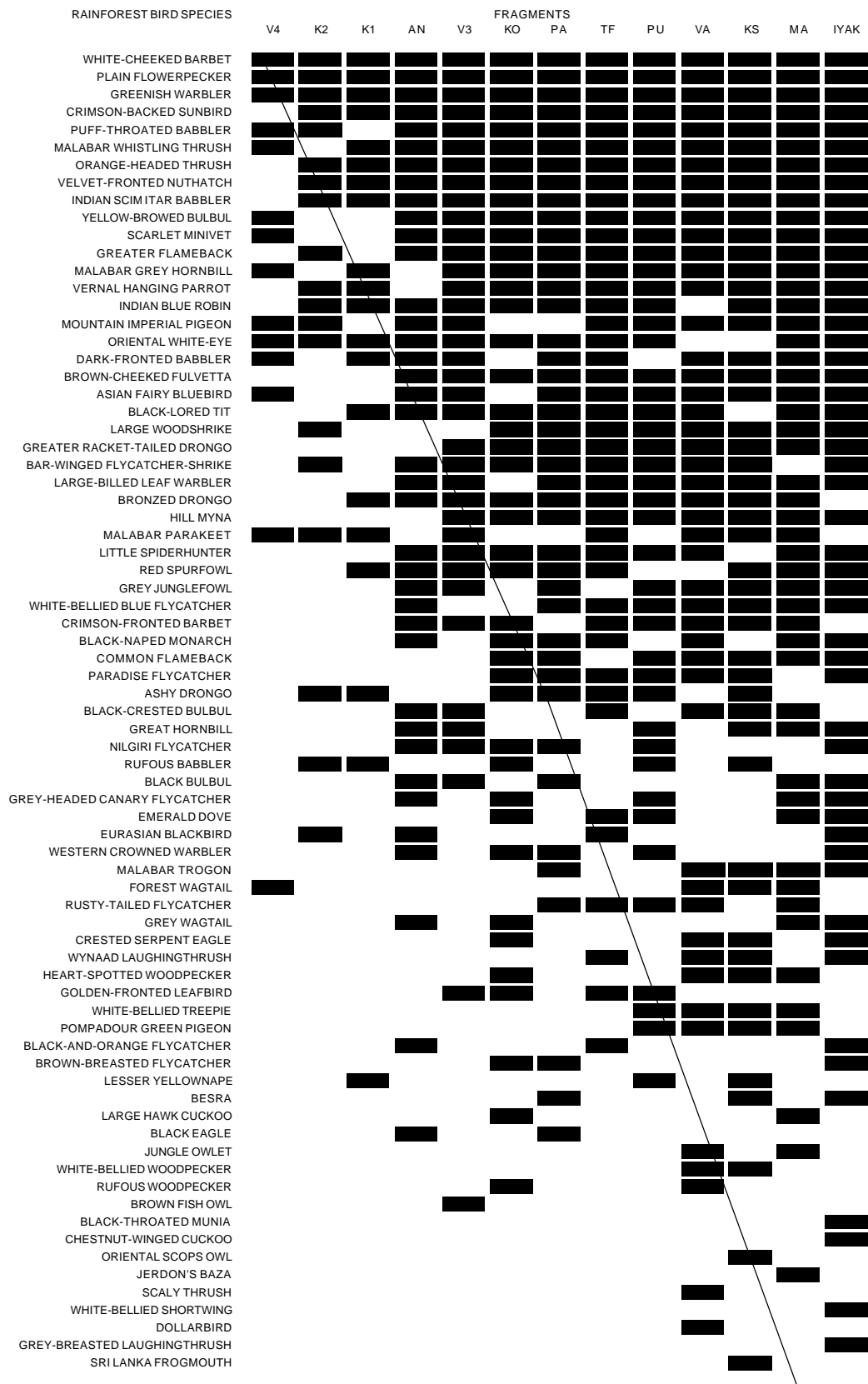
Figure 9: Nested distributions of rainforest bird species across fragments: results of nested subsets analyses using the program NESTCALC. The line can be taken to indicate an extinction threshold determined from the data. Each black bar represents the occurrence of a species (row) in the corresponding fragment (column).
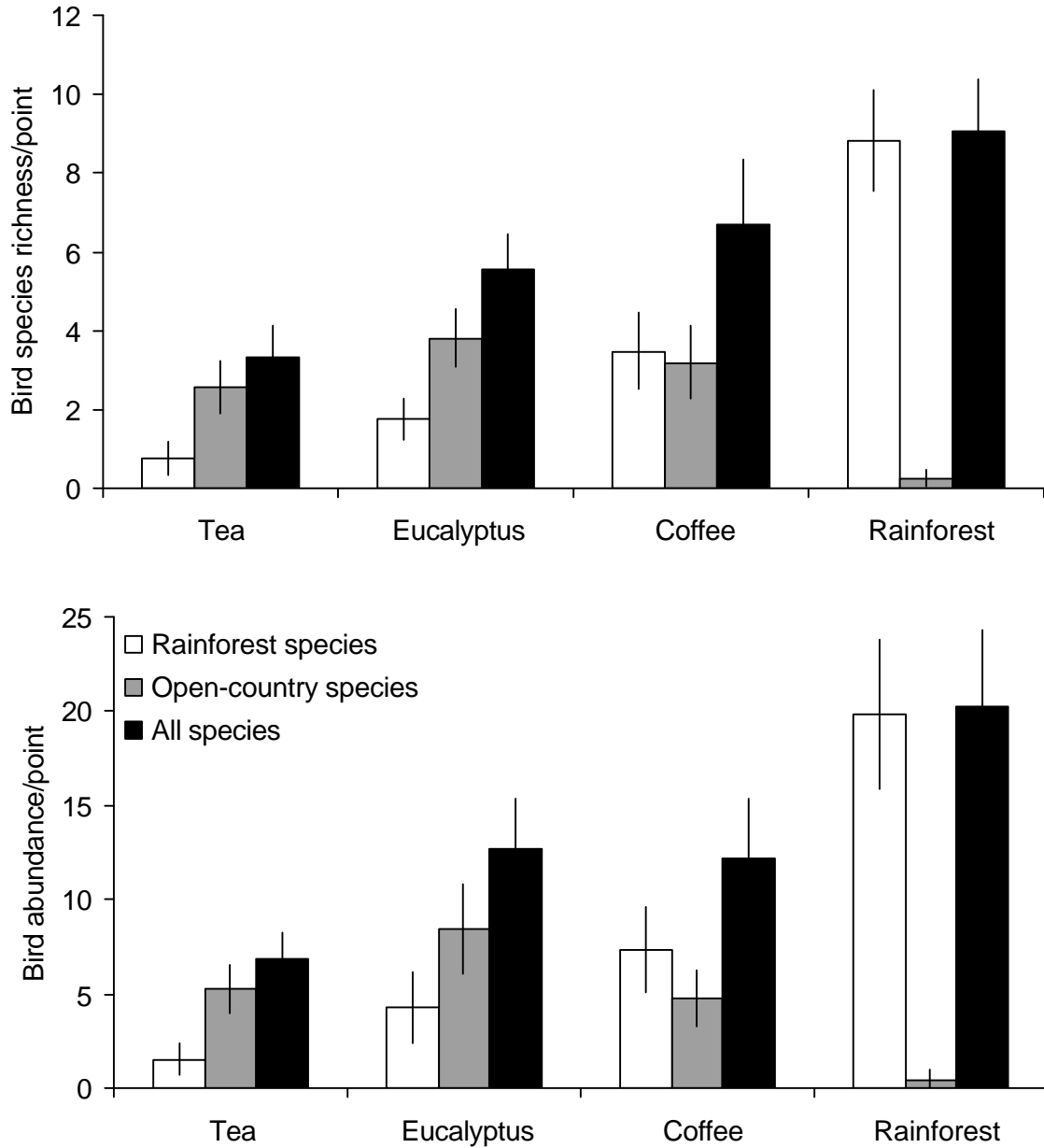
Figure 10: Bird species richness (a, upper panel) and bird abundance measured as number of individuals (b, lower panel) in the three plantation types and the control primary rainforest site in the Anamalai hills. Bars indicate average per point count sample with errors bars indicating ± 1 SE.

$H > 34.9$, $P < 0.0001$). The average richness and 95% confidence interval for each stratum is presented in Figure 10a. Total and rainforest bird species richness per point increased significantly from tea to *Eucalyptus* and coffee plantations and to rainforest. Open-country bird species richness was significantly lower in rainforest and roughly the same in all plantation types. Bird abundance per point also showed a similar pattern (Figure 10b). Rainforest bird abundance was over ten times higher in rainforest than in tea plantation, and over twice the abundance in coffee plantation.

4.3.2 *Effects of matrix on species survival in fragments*

The relative tolerance of rainforest bird species to the matrix of plantations was classified into three categories: matrix intolerant (17 species that occurred in the rainforest but were absent from the plantations), intermediate tolerance (species that used both the matrix and rainforest), high tolerance (species that appeared to be confined to plantations but were actually only encountered more frequently in plantations). Two main questions were addressed. First, did bird species that differed in their matrix tolerance also differ in the average densities they attained in small and medium-sized rainforest fragments? Second, was matrix tolerance related to species persistence in small and medium-sized fragments? Persistence was measured by a simple index: the ratio of average density in small (or medium-sized) fragments to average density in large fragments. Persistence index (PI) values > 1 indicated species whose population densities were higher in the smaller fragments, whereas index values < 1 indicated species that declined and 0 indicated species that disappeared in the fragments of the smaller size class.

The results in Table 10 illustrate the influence of matrix tolerance on species persistence in fragments. Species density varied significantly across tolerance categories: the species classified as intermediate in matrix tolerance occurred in all fragment size classes at higher densities than species

Table 10: Density and persistence of rainforest birds in different-sized fragments in relation to their tolerance of the landscape matrix of plantations in the Anamalai hills.

Parameter	Matrix tolerance[a]			*Kruskal-Wallis ANOVA*	
	Intolerant $N = 17$	Intermediate $N = 20$	High $N = 14$	H	P
Density in individuals/ha (SE)					
In small fragments	0.11 (0.04)	0.50 (0.13)	0.18 (0.08)	12.17	0.0023
In medium-sized fragments	0.29 (0.10)	0.68 (0.12)	0.17 (0.05)	14.12	0.0009
In large fragments	0.49 (0.16)	0.58 (0.10)	0.16 (0.05)	13.47	0.0012
Persistence[b] (SE)					
In small fragments	0.47 (0.22)	0.86 (0.13)	6.08 (2.81)	7.26	0.0265
In medium-sized fragments	0.98 (0.31)	1.28 (0.14)	10.67 (6.87)	5.57	0.0618

[a]—Intolerant = avoids matrix, Intermediate = uses matrix and rainforest, High = more frequent in matrix; *N* = number of bird species in each tolerance category.
[b]—Persistence was estimated for each species as the ratio of average density in that fragment class to the average density in large fragments.
Tabled values are means and SE calculated across the *N* species in each tolerance category.

of low tolerance. Surprisingly, species of high matrix tolerance also attained low densities (Table 10) in fragments of all size classes. This must be weighed against the fact that many of these species would have been rarer or absent as they were rainforest birds of lower-elevations. The densities of species in smaller fragments must be viewed relative to densities attained in the large fragments and this is done by the persistence index.

Analysis of species persistence indicated clearly an increase in persistence in relation to increasing tolerance of matrix, particularly in the bird community of small fragments (Table 10). Thus species that are highly tolerant of the matrix occur at much higher densities in small fragments than in the large fragments (average PI = 6.08). Species of intermediate tolerance occur at only slightly lower densities (average PI = 0.86) than in large fragments, whereas densities of matrix-intolerant species are much lower (average PI = 0.47). In medium-sized fragments, even matrix-intolerant species appear to persist, while more tolerant species increase substantially in abundance. The species of birds that occur in fragments and their abundances are thus linked to their tolerance of human-altered habitats such as plantations in the surrounding landscape.

4.4 Responses of diet-guilds and species categories

4.4.1 *Diet-guilds*

The number of bird species in different diet-guilds showed two main trends in relation to fragmentation. Bark-surface feeders, carnivores, omnivores, frugivores, understorey and terrestrial insectivores appeared to increase in species richness with fragment area. Nectarivore and canopy insectivore species richness was not directly related to fragment area, tending to be higher in medium-sized fragments (Table 11).

Regression analyses showed that bark-surface feeder, frugivore, and terrestrial insectivore species richness increased primarily in response to increasing fragment area (Table 11). Carnivores also responded mainly to fragment area—the significant positive relation with isolation in Table 11 is due to more species being recorded from the fragments at lower elevations (PA, MA, KS, and VA) that were also the most distant ones from the IYAK control site. Low-elevation sites also had more species of omnivores as indicated by the significant negative regression coefficient in Table 11. Nectarivores showed no significant relationship with measured parameters. The only guilds that showed strong relationships with habitat measures were the canopy and understorey insectivores. Species richness of both these guilds was positively associated with PC1, indicating that fragments with better forest structural development and higher shrub density tended to contain more species in these guilds (Table 11).

Within each guild, species showed a diversity of responses ranging from being nearly ubiquitous to being confined to large fragments or those that contained well-developed habitat structure (Appendix 4). Bark-surface feeders, carnivores, omnivores, frugivores, and understorey

Table 11: Species richness of diet-guilds and different bird species categories in relation to area, habitat, altitude, and isolation of rainforest fragments in the Anamalai hills—results of stepwise multiple regression analyses.

	Beta (standardised regression coefficient)					Regression ANOVA				Kendall
	Log(area)	PC1	PC2	Altitude	Isolation	R^2	F	df	P	correlation[a]
Diet-guild										
Bark-surface feeder	0.659**	–	–	–	0.359[+]	0.859	16.32	3,8	0.0009	0.641**
Omnivore	–	–	–	−0.427[+]	–	0.712	6.60	3,8	0.0148	0.586**
Carnivore	0.424[+]	–	–	–	0.785*	0.811	11.44	3,8	0.0029	0.642**
Frugivore	0.788**	–	–	–	–	0.620	16.35	1,10	0.0024	0.541**
Nectarivore	–	–	–	–	–	–	–	–	–	0.014
Canopy insectivore	–	0.534*	−0.475[+]	–	–	0.531	5.10	2,9	0.0331	0.259
Understorey insectivore	0.440[+]	0.632*	–	0.286[+]	–	0.849	15.02	3,8	0.0012	0.568**
Terrestrial insectivore	0.624[+]	–	–	–	–	0.295	1.89	2,9	0.2068	0.403[+]
Species category										
All migrants	–	–	–	–	–	–	–	–	–	0.235
Open-country migrants	–	−0.565*	−0.646**	–	–	0.709	10.95	2,9	0.0039	−0.424*
Rainforest migrants	–	–	–	–	–	–	–	–	–	0.390[+]
Endemic species	0.475[+]	–	–	–	–	0.628	7.60	2,9	0.0117	0.688***
Priority species	0.585*	0.277[+]	–	−0.251[+]	–	0.907	25.87	3,8	0.0002	0.658**

[a]—Kendall rank-order correlation coefficients with log(area) of fragment
[+]—$P < 0.15$, *—$P < 0.05$, **—$P < 0.01$, ***—$P < 0.001$ ($N = 13$ fragments)

insectivores were all represented by fewer than three species in the three smallest fragments (up to 1 ha in area) and more species in larger fragments.

4.4.2 *Migrants, endemics, and priority species*

The number of species of migrants, Western Ghats endemics, and priority (rare, restricted-range, discontinuously distributed, and threatened) species were also analysed in relation to fragment area, isolation, altitude, and habitat. Among migrants, no trends were evident when all species or rainforest species were considered. The number of species of open-country migrants was negatively related to both PC1 and PC2 and also showed a trend of decrease with fragment area (Table 11). A noteworthy pattern is that both the number of endemic species and number of priority species was mainly related to fragment area. Priority species richness was also weakly positively associated with forest structural development (PC1) and tended to decline with increasing elevation (Table 11).

Within each category also species showed a diversity of responses. Among the 11 endemic species recorded during the study, five (Malabar Parakeet, Malabar Grey Hornbill, Nilgiri Flycatcher, Rufous Babbler, Crimson-backed Sunbird) were seen in fragments less than 10 ha in area. Medium-sized (10–100 ha) fragments contained these five plus an additional four species (Black-and-Orange Flycatcher, White-bellied Treepie, White-bellied Blue Flycatcher, Wynaad Laughingthrush). Only two species appeared to be restricted to the largest fragments (Grey-breasted Laughingthrush, White-

bellied Shortwing), both being high-altitude forms seen in the Akkamalai portion of the control site and unlikely to occur in the lower elevation fragments. Both these species may occur in smaller fragments at higher elevations. Among the 24 priority rainforest bird species, only six were confined to large fragments (Dollarbird, Sri Lanka Frogmouth, White-bellied Woodpecker, Jerdon's Baza, Black-throated Munia, Scaly Thrush, the first three being low-elevation species). Eight species were widespread from the smallest to the largest fragments, and ten species occurred in medium and large fragments. It must be noted that species distributions may not have been related merely to fragment area. For instance, the Malabar Trogon, was found in all large fragments, but occurred in the 10 ha Pannimade fragment in which the habitat was relatively undisturbed.

5. DISCUSSION

The major effects of fragmentation on bird communities in this study are clear. Trends in bird species richness were related to fragment area and habitat and were not predicted by null models of passive sampling. With increasing area of the fragment, the species richness of rainforest birds increases log-linearly. Besides area, the structural development of rainforest vegetation (PC1) had positive effects on rainforest birds (increasing richness and similarity with the control site) and negative effects on open-country species. Bird community composition was also predictably related to site and habitat features and showed a nested subsets structure, indicating possible differential extinction of species in relation to fragmentation. Plantations, particularly tea and *Eucalytptus* and to a lesser extent coffee, had deleterious effects on a large number of rainforest bird species, although birds that tolerated or thrived in plantations were able to persist in small and medium-sized fragments also, and often at higher densities. Diet-guilds and species categories showed varying responses to fragmentation, with endemics, priority species, and diet-guilds such as carnivores, frugivores, bark-surface feeders, and understorey insectivores appearing to be particularly susceptible. The diversity of responses across species indicates that the observed effects are a consequence of various underlying factors and mechanisms.

5.1 Biological infiltration

A primary consequence of rainforest fragmentation and conversion to plantations in the Valparai landscape has been the influx of at least 25 species of open-country birds (21.3% of species recorded in the study). These non-rainforest birds include species such as Ashy Prinia, Common Tailorbird, Red-whiskered Bulbul, Golden Oriole, Grey-headed Myna, Asian Brown Flycatcher, Magpie Robin, and Chestnut-tailed Starling that are typically found in tropical dry thorn and dry deciduous forests in the adjoining areas of the Anamalai hills as well as over most of the Indian sub-continent (Ali and Ripley 1983, Daniels 1997). These species have successfully colonised and utilise the small and medium-sized fragments, particularly highly disturbed sites such as Korangumudi, in which a number

of rainforest bird species appear to be locally extinct. The replacement of rainforest birds typical to a region by widespread species of open-country following human-caused habitat alteration has also been noted in earlier studies (Leck 1979, Daniels *et al.* 1990a, 1992, Raman *et al.* 1998, Raman 2001).

It has been widely recognised that non-forest and second-growth species may occur at the periphery of fragments due to *edge effects*, particularly within 100 m from the periphery of fragments (Lovejoy *et al.* 1986, Wiens 1989, Malcolm 1994, Murcia 1995, Restrepo and Gomez 1998). In the present study, open-country birds not only occurred along fragment edges, but were regularly seen in the interior of medium-sized fragments, even over 100 m from the edge. This is mainly attributable to the habitat disturbance (particularly tree cutting for fuelwood and timber) that opened up the canopy and understorey all across the fragment. The consequent structural changes as well as growth of deciduous and pioneer tree species (e.g., *Macaranga peltata*) increase the resemblance of these fragments to more open deciduous forests while decreasing their similarity with undisturbed primary rainforest. This then enables open-country species to colonise even the interior of fragments and not merely the edges. This process of influx of non-forest species replacing forest species in local communities can be termed *biological infiltration* as the colonising species are often found in the interior of fragments. This phenomenon is not a result of fragmentation *per se* because small and isolated fragments such as Pannimade that were less disturbed had fewer (8) open-country species than highly disturbed fragments of similar size (V3, 13 species) or larger (KO, 21 species). Biological infiltration as seen here is also distinct from biological invasions, which typically involve the proliferation of a few, mostly weedy, often exotic, species. Infiltration, in contrast, involves species native to regional habitats establishing in atypical habitats, at large or sparse population sizes. Such a process has been noted in studies ranging from beetles in fragmented temperate deciduous forests (Ås 1999), butterflies in Amazonia (Brown and Hutchings 1997), and reptiles (Ishwar 2001) and small carnivorous mammals (Mudappa 2001) in the fragments of the Anamalai hills.

The infiltration of species is a matter of conservation concern as widespread species of drier forests benefit at the cost of more restricted, often rare, rainforest species, whose conservation is of higher priority (Usher 1986). The cessation or reversal of rainforest habitat alteration that creates more openings is required through protection or restoration for the maintenance of rainforest bird community structure.

5.2 Bird species richness: area *versus* habitat effects

The above process of biological infiltration of open-country birds into rainforest areas leads to the pattern of higher overall bird species richness in medium-sized fragments. Species richness of typical rainforest birds, in contrast, shows the more common trend of increase with area of fragments (Wiens 1989, Bolger *et al.* 1991, Newmark 1991, Bellamy *et al.* 1996, Turner 1996). This pattern is likely to

have been accentuated if sampling effort had been in proportion to area. Supplementary observations and earlier published records indicate that a number of carnivores, in particular, too rare to have been recorded in point count surveys are also largely confined to large fragments. This includes the Oriental Bay Owl and Spot-bellied Eagle Owl in Karian Shola (Kannan 1993, 1998, Mudappa 1998b), Mountain Hawk Eagle in Varagaliar (A. Kumar, personal communication), Blue-eared Kingfisher in Manamboli, and Rufous-bellied Eagle in Akkamalai (personal observations). Some of these species may require large forest areas due to their large home range requirements; for instance, Thiollay and Meyburg (1988) report that Rufous-bellied Eagles have home range sizes of $20 - 30$ km² in Java and may not occur in forest patches smaller than $20 - 100$ km².

On the other hand, only 11 bird species were seen occurring exclusively in fragments larger than 1,000 ha in this study. Of these, five were low-elevation birds (Jungle Owlet, Oriental Scops Owl, Dollarbird, Sri Lanka Frogmouth, White-bellied Woodpecker), and two were high-elevation species (Grey-breasted Laughingthrush, White-bellied Shortwing), all of which may occur in smaller fragments at the corresponding elevations (such fragments were not sampled during this study). The remaining five species were seen infrequently and their absence from even medium-sized fragments may indicate greater rarity rather than local extinction in such fragments.

The number of species in fragments was not a simple result of passive sampling in relation to area as noted by Coleman *et al.* (1982) for breeding birds on islands in the Pymatuning lake in North America and by Haila *et al.* (1993) for breeding birds in the Finnish Taiga. This model often results in virtually all individuals 'gathering' in the largest fragment (2,600 ha in this study, $p_{area} = 0.451$) while small ones receive very few individuals due to their small proportional area (K2 = 0.30 ha, p_{area} = 0.005). This may be a realistic model in cases where a large habitat patch is suddenly broken up into islands (e.g., because of creation of a reservoir that floods low areas and leaves peaks as islands) and for species that are relatively sedentary or dispersal-limited. For habitat islands that were created long ago and vagile taxa like birds, however, even small islands will eventually be colonised or used for foraging and breeding. This may lead to higher number of individuals on the island than expected under the area-based sampling model. This scenario was modelled through the abundance-based passive sampling, a process similar to the *ecological drift* model proposed recently by Hubbell (2001), but the model failed to accurately predict the observed pattern of species richness.

The failure of the null models and the strong correlations between species richness and measures of habitat structure (particularly PC1) indicate that bird community structure in fragments is more strongly moulded by habitat characteristics than by random-sampling dynamics and ecological drift. The observed species richness of the three largest fragments is $15 - 21\%$ lower than expected under the abundance-based passive sampling model. This is mainly because many low-elevation species do not occur in the IYAK fragment and high-elevation species do not occur in KS and VA, although under the null model these inter-specific differences are ignored and virtually all species are

expected to occur in all large fragments by chance alone. The disproportionately fewer species than expected in the smallest fragments is due to the additional process of local extinction of many rainforest bird species in these fragments because they contain insufficient area or habitat resources for those species. Similar results have been obtained for birds of urban chapparal fragments in California (Bolger *et al.* 1991). The results suggest that models of fragmentation that do not consider all species or individuals as equivalent but allow species-specific variation in tolerance for fragment attributes are likely to be of greater predictive power.

5.3 Species turnover

Bird species turnover is likely to be mainly influenced by geographic factors under a system of non-equilibrium colonisation-extinction dynamics as proposed under the island biogeography theory of MacArthur and Wilson (1967) and the ecological drift model of Hubbell (2001). Fragments are likely to be more similar to each other in bird community composition the more similar they are in area and the closer they are to each other. On the other hand, community composition could be more deterministic, with species occurrences and abundances depending on site-specific habitat structure and resource availability. In a slash-and-burn habitat mosaic in tropical rainforests of northeast India, the degree of alteration of bird community composition in successional sites in comparison to primary forest was found to be predictably and strongly related to the degree of change in habitat structure and tree species composition of these sites as compared to primary forest (Raman *et al.* 1998).

In the Valparai landscape, both geographic and habitat factors influence bird species turnover. The similarity in bird community composition of rainforest fragments from the control site (IYAK) tended to decrease with increasing geographic distance from IYAK as well as with increasing difference in area with it. The effect of geographic distance is expected as fragments were often highly isolated by surrounding tea estates, plantations, or reservoirs, and the dynamics of fragments farther away is likely to have been independent of the control site. In addition, however, there was a significant influence of floristics—fragments that were similar in tree species composition with IYAK tended to also be similar in their bird communities. This is well illustrated by the Pannimade (PA) fragment, which was relatively undisturbed in habitat structure and tree species composition when compared to the control site. Although PA was the most isolated fragment (excluding the two northernmost fragments, VA and KS) from the control site, it was more similar to the control site than closer sites such as Puthuthottam. The influence of tree species composition on bird community composition is similar to the findings of Raman *et al.* (1998) along a rainforest successional gradient as well as the results from studies of rainforest bird communities along altitudinal and disturbance gradients in the Kalakad-Mundanthurai Tiger Reserve (T. R. S. Raman unpublished data). This is possibly brought about by the occurrence of nectarivorous and frugivorous birds, which are likely to

be directly related to the floristic composition, and even some insectivorous species, which may have specific tree species preferences for foraging (Robinson and Holmes 1984).

Determinism in species turnover is also revealed in the significant nested subsets structure in bird community composition. Nested subsets structure has been recorded in a wide variety of communities spanning taxonomic categories from butterflies to mammals and across temperate and tropical regions (Wright *et al.* 1998). Such a pattern can emerge due to different processes: passive sampling, area or distance effects, and nestedness of microhabitats (Wright *et al.* 1998). Passive sampling is unlikely to be an explanation of the nestedness observed in this study. The passive sampling models that failed to predict observed patterns of species richness are unlikely to predict observed patterns of species composition. Under passive sampling, one would expect a positive relation between distribution and abunance, with abundant species represented in all fragments and rare species in fewer sites (Wright *et al.* 1998). In the present study, three ubiquitous species were among the most abundant ones (Plain Flowerpecker, White-cheeked Barbet, Greenish Leaf Warbler). However, other abundant species such as Yellow-browed Bulbul and Brown-cheeked Fulvetta did not actually occur in small fragments although they would be expected to occur under a passive sampling situation.

Area, at first, appears to be a major factor influencing nested subsets structure. A number of species did not occur in fragments less than 10 ha in area. This area may have been insufficient to meet the home range requirements of species such as Malabar Trogon, Emerald Dove, Crested Serpent Eagle, and Greater Flameback. Other species absent from small fragments were those which probably had small home ranges; for example, six of the seven species of flycatchers recorded during the study from rainforests (the seventh species, Nilgiri Flycatcher, occurred but at lower densities, see Appendix). The absence of these birds and other small birds such as Dark-fronted Babbler, Large-billed Leaf Warbler, and Black-throated Munia, indicates that it is not area *per se* but probably the changes in habitat that lead to the selective local extinction of these species.

On the other hand, a majority of species occurred in medium-sized fragments (taken together and including those with relatively undisturbed rainforest vegetation such as Pannimade) as well as in large fragments. Many species that were apparently restricted to the largest fragments in this study may have been so restricted, not due to area limitation, but due to altitudinal distributions and habitat structure. These typically low- or high-elevation species may occur in fragments below 700 m or above 1,500 m, which could be confirmed for a few species during this study (Grey-breasted Laughingthrush, White-bellied Shortwing).

Many species were probably responding more directly to habitat structure than area *per se.* For instance, the Malabar Trogon was seen only in the Pannimade fragment (10 ha) and the large fragments and not in any of the small or medium-sized fragments. This can be explained by the fact that only Pannimade and the large fragments had a relatively undisturbed rainforest habitat strcuture. That species may be nested in relation to other factors such as fragment isolation, habitat structure, or

the nested distribution of microhabitats, with considerable variation across species and species categories, as noted in other studies also (Simberloff and Martin 1991, Kadmon 1995, Calmé and Desrochers 1999).

Nested subsets structure and the high similarity in species composition among small fragments has implications for the SLOSS (Single Large Or Several Small reserves) debate. The deterministic pattern of species loss indicates that even a number of small, species-poor fragments, particularly those less than 10 ha, are likely to never contain all the species in a single large site (Bolger *et al.* 1991, Worthen 1996). It could be argued from the results of this study, however, that a set of medium-sized (10–100 ha) fragments could potentially harbour all the species found in an equivalent area of a single large fragment. This however may not be tenable in a landscape where there are only small or medium-sized fragments. Many of the species observed in small- or medium-sized fragments are individuals that are temporary visitors or settlers from adjoining large fragments. This is illustrated by the observation of Great Hornbills in a 7 ha fragment that was surrounded by shade-coffee and within flight distance (< 2 km) of other medium and large fragments. In the absence of large fragments in the landscape, further depauperisation of the bird communities of fragments is likely to occur, due to lack of source pools for species to disperse from.

5.4 Plantations and matrix tolerance

Tea and *Eucalytptus* plantations have a predominantly detrimental effect on rainforest birds being dominated by widespread, common, open-country bird species such as Red-whiskered Bulbul, Blyth's Reed Warbler, Ashy Prinia, and Common Tailorbird. Coffee plantations as they retain some shade trees support many more rainforest bird species. As none of the plantations support all rainforest bird species, the importance of retaining natural rainforest cover is paramount. Similar patterns have been noted by Daniels *et al.* (1990) in bird communities in Uttara Kannada district. The influence of rainforest habitat structure and tree species composition on the rainforest bird community has been documented earlier. Among existing plantation areas, shade-coffee plantations resemble rainforest in structure and floristics to a greater extent than tea or *Eucalyptus*, thereby accounting for their greater bird diversity and similarity with primary rainforest. Measures to retain and encourage shade-coffee in preference to or in order to replace other sorts of plantations without native shade trees is therefore likely to have beneficial effects for bird conservation. Tea and shade-coffee plantations often abut protected areas all along the Western Ghats and these man-made habitats are used by many wildlife species. Given their location and areal coverage, these habitats, particularly shade-coffee plantations cannot be ignored for wildlife conservation policies.

The role of shade-coffee plantations in supporting many tropical forest birds has received much recent international attention (Greenberg *et al.* 1997a, b, Wunderle 1999, Sherry 2000). In the Anamalai hills, plantations, particularly shade-coffee, have beneficial effects on a number of

rainforest bird species by allowing them to persist in small and medium-sized fragments, often at higher densities. This may be due to the ability of these species to exploit resources from the surrounding matrix to support higher populations within fragments. Another possibility is that following the local extinction of matrix-intolerant rainforest species, the remaining species increase in abundance due to density compensation effects. This process, along with the infiltration of open-country species, may also explain the constancy of total bird density across the entire range of fragment sizes in this study.

5.5 Responses of bird species categories

Although responses of birds varied both within and across species categories, some broad patterns were evident. Among different diet-guilds, those that included many large and wide-ranging species appeared to be area-sensitive: bark-surface feeders, frugivores, and carnivores (woodpeckers, hornbills, imperial pigeons, hawks, and eagles). In addition, terrestrial insectivores too appeared to be sensitive to fragmentation, a pattern also noted in Amazonian tropical rainforest (Canaday 1996, Stratford and Stouffer 1999). The species richness of canopy and understorey insectivores, which constitute a sizable fraction of tropical rainforest bird communities, appeared to be related mainly to habitat structure. The availability of adequate foraging and nesting substrate may be more critical to these species than fragment area *per se*. Nectarivore species richness was unrelated to fragment area, possibly because these small-bodied species have small home range requirements, and even small fragments probably contained sufficient nectar and arthropod resources to meet their requirements. A similar pattern has been noted in Central Amazonia, where hummingbirds have been noted to be less susceptible to forest fragmentation (Stouffer and Bierregaard 1995b) than other guilds such as understorey or terrestrial insectivores (Stouffer and Bierregaard 1995a). Omnivores too, presumably because of their dietary flexibility, are widely distributed across fragment size classes, although more species occur at lower altitudes (as seen in undisturbed rainforests elsewhere, T. R. S. Raman, unpublished data) possibly due to higher productivity or availability of resources.

A result of particular conservation concern is the higher number of endemic and priority bird species in larger fragments. This underscores the need for maintenance of large tracts of tropical rainforest for bird conservation. As noted earlier, however, it is not merely area, but habitat structure that is also likely to be an important determinant of distribution and abundance of these species. It is likely that a greater number and abundance of endemic and priority species can be retained in the small and medium-sized fragments in the landscape, if the habitat was relatively undisturbed in these fragments.

5.6 Conservation implications

The conservation implications that emerge from the above results and discussion can be summarised in the following main points:

1. **ALASS, not SLOSS:** The guiding paradigm for conservation in fragmented landscapes should not be a debate over conservation of single large *or* several small reserves, but instead, emphasise the need to protect and conserve *All Large And Several Small* (ALASS) remnants of natural habitat. This 'have the cake and eat it too' paradigm may seem unrealistic or impracticable in real-world situations, but is certainly the target to aspire for. In the Anamalai hills, small (< 10 ha) and medium (10−100 ha) fragments play important roles in maintaining larger populations of rainforest birds in the landscape, providing habitat for altitudinal migrants, and increasing dispersal connectivity between areas. The conservation of fragments of all sizes cannot be ignored.

2. **Rainforest habitat restoration:** The deterioration of habitat structure in fragments due to disturbance has detrimental effects on rainforest birds. Many isolated fragments are now in a situation where mere protection will not suffice and is unlikely to result in full or rapid recovery. Active efforts to restore and improve rainforest habitat structure and tree species composition are needed for conservation of the rainforest bird community typical to the region. Many fragments currently continue to be disturbed due to removal of trees and fuelwood by local people. Conservationists, forest departments, and private companies and landowners need to work together to devise strategies and provide alternative fuel supplies for local people to reduce these impacts on fragments. Incentives for people to switch to liquefied petroleum gas available through outlets in Valparai need to be pursued urgently and vigorously.

3. **Role of shade-coffee plantations:** Coffee plantations with a mixture of native rainforest tree species in the canopy for shade are a relatively low-impact form of land-use, allowing the persistence of many rainforest birds within them as well as in adjacent fragments. Recent trends of conversion of shade-coffee to tea plantations in the Anamalai hills are, therefore, of great concern. Over the last two months as this chapter was written (August − September 2001), over 35 hectares of shade-coffee around the Korangumudi fragment have been completely cleared of all tree cover and planted with tea. There is an obvious need to curtail such transformations which have negative consequences in crucial conservation areas such as the Anamalai hills, not just locally but even at a landscape level. Also, there is a need to explore positive economic (tax, pricing) incentives for landowners to retain or enhance the area under such shade-coffee plantations in preference to areas under tea and *Eucalyptus*.

4. **Research needs:** Several questions remain before the effects of fragmentation on rainforest birds can be fully understood and effective management steps devised. This includes aspects known to have significant influences in other fragmented forests. Factors requiring study include edge

effects, population trends and demography of birds in small and large fragments, effects of overstorey tree species composition in shade-coffee estates on bird community similarity with primary rainforest, bird community structure in fragments surrounded by different kinds of matrix habitats, influence of nest predation on species survival in fragments, and recovery of rainforest birds in restored areas.

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APPENDIX

Densities of rainforest birds (number of individuals/ha) estimated from fixed-radius point counts across the 13 rainforest fragments in the Anamalai hills. Western Ghats endemics are marked (*). Bird species are listed alphabetically within habitat preferences: RF = rainforest birds, OC = Open-country birds. *N* = Number of detections (encounters) of species across sites in point-count surveys. Common names as in Grimmett *et al.* 1998.

Species	K2	K1	V4	V3	PA	TF	KO	PU	AN	MA	KS	VA	IYAK	Habitat	*N*
Ashy Drongo	0.32	0.18	-	-	0.25	0.04	0.38	0.04	-	-	0.03	-	-	RF	15
Asian Fairy Bluebird	-	-	0.42	0.13	0.25	0.42	-	0.13	0.12	0.99	0.57	0.93	0.34	RF	65
Asian Paradise Flycatcher	-	-	-	-	0.13	0.04	0.13	0.04	-	-	0.03	0.08	0.02	RF	12
Bar-winged Flycatcher-Shrike	0.32	-	-	0.06	0.3	0.08	0.3	0.13	0.18	-	0.06	0.04	0.17	RF	23
Besra	-	-	-	-	0.13	-	-	-	-	-	0.03	-	0.07	RF	8
Black Bulbul	-	-	-	0.06	0.04	-	-	-	1.88	0.03	-	-	1.53	RF	81
Black Eagle	-	-	-	-	0.04	-	-	-	0.06	-	-	-	-	RF	2
Black-and-Orange Flycatcher*	-	-	-	-	-	0.08	-	-	0.52	-	-	-	0.54	RF	32
Black-crested Bulbul	-	-	-	0.51	-	0.42	-	-	0.06	0.28	0.25	0.34	-	RF	23
Black-lored Tit	-	0.36	-	0.13	0.25	0.3	0.38	0.13	0.36	0.06	-	0.08	0.14	RF	24
Black-naped Monarch	-	-	-	-	0.64	0.17	0.21	-	0.12	0.28	-	0.85	0.25	RF	54
Black-throated Munia	-	-	-	-	-	-	-	-	-	-	-	-	0.19	RF	3
Bronzed Drongo	-	0.73	-	0.51	0.47	0.59	0.68	1.06	0.06	0.71	0.22	0.3	-	RF	60
Brown Fish Owl	-	-	-	0.06	-	-	-	-	-	-	-	-	-	RF	1
Brown-breasted Flycatcher	-	-	-	-	0.04	-	0.04	-	-	-	-	-	0.02	RF	3
Brown-cheeked Fulvetta	-	-	-	0.45	3.73	0.55	0.93	0.51	3.76	2.63	0.25	3.61	2.94	RF	86
Chestnut-winged Cuckoo	-	-	-	-	-	-	-	-	-	-	-	-	0.02	RF	1
Common Flameback	-	-	-	-	0.17	-	0.13	0.34	-	0.31	0.13	0.17	0.03	RF	20
Crested Serpent Eagle	-	-	-	-	-	-	0.08	-	-	-	0.03	0.04	0.02	RF	5
Crimson-backed Sunbird*	0.32	0.36	-	0.64	2.25	1.78	0.34	0.89	1.18	1.7	0.19	1.36	1.66	RF	266
Crimson-fronted Barbet	-	-	-	0.38	-	0.08	0.04	0.81	0.24	0.28	0.64	0.59	-	RF	41
Dark-fronted Babbler	-	0.55	1.06	0.76	0.21	1.4	-	-	0.33	0.37	0.06	0.13	0.15	RF	30
Dollarbird	-	-	-	-	-	-	-	-	-	-	-	0.13	-	RF	3
Emerald Dove	-	-	-	-	-	0.13	0.08	0.04	-	0.28	-	-	0.03	RF	15
Eurasian Blackbird	0.64	-	-	-	-	0.13	-	-	0.03	-	-	-	0.12	RF	9

Species	K2	K1	V4	V3	PA	TF	KO	PU	AN	MA	KS	VA	IYAK	Habitat	N
Forest Wagtail	-	-	0.21	-	-	-	-	-	-	0.17	0.03	0.04	-	RF	9
Golden-fronted Leafbird	-	-	-	0.13	-	0.13	0.17	0.08	-	-	-	-	-	RF	6
Great Hornbill	-	-	-	0.13	-	-	-	0.04	0.09	0.08	0.16	-	0.14	RF	11
Greater Flameback	0.64	-	-	0.25	0.34	0.25	0.47	0.17	0.24	0.42	0.19	0.51	0.27	RF	46
Greater Racket-tailed Drongo	-	-	-	0.32	1.23	0.3	0.13	0.08	-	0.76	1.4	1.57	0.15	RF	87
Greenish Leaf Warbler	0.32	1.09	1.27	0.83	1.4	0.85	1.4	1.53	1.06	0.45	0.32	0.42	0.73	RF	262
Grey Junglefowl	-	-	-	0.19	0.25	-	-	0.13	0.21	0.23	0.48	0.04	0.22	RF	34
Grey Wagtail	-	-	-	-	-	-	0.04	-	0.03	0.03	-	-	0.02	RF	4
Grey-breasted Laughingthrush*	-	-	-	-	-	-	-	-	-	-	-	-	0.17	RF	1
Grey-headed Canary Flycatcher	-	-	-	-	-	-	0.08	0.13	1.58	0.06	-	-	1.41	RF	74
Heart-spotted Woodpecker	-	-	-	-	-	0.08	-	-	0.06	0.25	0.17	-	-	RF	8
Hill Myna	-	-	-	0.13	0.85	0.3	0.25	1.32	-	0.59	0.45	1.36	0.44	RF	82
Indian Blue Robin	0.32	0.55	-	0.25	0.21	0.13	0.17	0.08	0.09	0.28	0.03	-	0.12	RF	43
Indian Scimitar Babbler	1.27	0.73	-	1.02	1.57	0.55	0.34	1.15	0.79	0.62	0.06	0.51	0.75	RF	98
Jerdon's Baza	-	-	-	-	-	-	-	-	0.03	-	-	-	-	RF	1
Jungle Owlet	-	-	-	-	-	-	-	-	0.06	-	0.08	-	-	RF	2
Large Hawk Cuckoo	-	-	-	-	-	0.04	-	-	0.03	-	-	-	-	RF	2
Large Woodshrike	0.32	-	-	-	0.13	0.38	0.76	0.3	-	0.11	0.06	0.17	0.07	RF	35
Large-billed Leaf Warbler	-	-	-	0.25	0.76	0.38	-	0.38	0.55	0.34	0.54	0.25	0.49	RF	121
Lesser Yellownape	-	0.18	-	-	-	-	-	0.04	-	-	0.06	-	-	RF	3
Little Spiderhunter	-	-	-	0.06	0.42	0.76	0.21	0.34	0.15	0.74	-	0.55	0.27	RF	83
Malabar Grey Hornbill*	-	0.18	0.21	0.19	0.17	0.08	0.34	0.25	-	0.59	1.4	0.76	0.07	RF	78
Malabar Parakeet*	0.32	1.64	1.91	0.06	-	0.81	-	-	-	0.85	0.6	0.55	-	RF	47
Malabar Trogon	-	-	-	-	0.17	-	-	-	-	0.17	0.22	0.25	0.07	RF	15
Malabar Whistling Thrush	-	0.55	0.21	0.25	0.85	0.47	0.25	0.81	0.33	1.16	0.92	1.1	0.42	RF	147
Mountain Imperial Pigeon	0.32	-	0.85	0.06	-	0.21	-	0.08	0.18	0.14	0.45	0.17	0.61	RF	58
Nilgiri Flycatcher*	-	-	-	0.06	0.47	-	0.17	0.08	0.76	-	-	-	0.73	RF	69
Orange-headed Thrush	0.64	0.55	-	0.32	0.42	0.08	0.13	0.47	0.49	0.34	0.57	0.21	0.2	RF	83
Oriental Scops Owl	-	-	-	-	-	-	-	-	-	-	0.03	-	-	RF	1
Oriental White-Eye	3.82	2.36	3.18	0.13	2.33	2.38	3.14	1.15	5.46	1.05	-	-	3.89	RF	117
Plain Flowerpecker	0.95	1.09	1.27	1.27	1.61	1.66	1.15	1.32	0.91	1.3	0.32	1.32	0.87	RF	270
Pompadour Pigeon	-	-	-	-	-	-	0.34	-	0.08	0.38	0.17	-	-	RF	11
Puff-throated Babbler	0.64	-	0.42	0.64	0.13	0.81	0.17	0.68	0.45	0.79	0.54	0.3	0.34	RF	116
Red Spurfowl	-	0.36	-	0.25	0.25	0.13	0.08	-	0.09	0.06	0.03	-	0.03	RF	15
Rufous Babbler	1.59	0.73	-	-	-	-	0.81	0.76	-	-	0.13	-	-	RF	13
Rufous Woodpecker	-	-	-	-	-	-	0.34	-	-	-	-	0.08	-	RF	5
Rusty-tailed Flycather	-	-	-	-	0.25	0.13	-	0.17	-	0.25	-	0.08	-	RF	24
Scaly Thrush	-	-	-	-	-	-	-	-	-	-	0.04	-	-	RF	1
Scarlet Minivet	-	-	2.33	0.83	0.17	0.25	0.98	1.06	0.52	0.54	0.45	0.64	0.37	RF	53
Sri Lanka Frogmouth	-	-	-	-	-	-	-	-	-	-	0.03	-	-	RF	1
Velvet-fronted Nuthatch	1.27	0.73	-	0.19	0.81	0.47	1.27	1.44	0.88	0.14	0.06	0.42	0.63	RF	76
Vernal Hanging Parrot	0.64	0.55	-	0.19	0.25	0.3	0.89	0.13	-	0.42	0.19	0.34	0.08	RF	68

Species	K2	K1	V4	V3	PA	TF	KO	PU	AN	MA	KS	VA	IYAK	Habitat	N
Western Crowned Warbler	-	-	-	-	0.25	-	0.34	0.21	0.3	-	-	-	0.1	RF	5
White-bellied Blue Flycatcher	-	-	-	-	0.25	0.17	-	0.08	0.09	0.65	1.08	0.38	0.1	RF	50
White-bellied Shortwing*	-	-	-	-	-	-	-	-	-	-	-	-	0.19	RF	11
White-bellied Treepie	-	-	-	-	-	-	0.08	-	0.2	0.6	0.25	-	-	RF	16
White-bellied Woodpecker	-	-	-	-	-	-	-	-	-	0.06	0.08	-	-	RF	2
White-cheeked Barbet	0.95	1.46	1.06	0.7	0.51	0.51	0.55	1.49	0.61	1.24	0.45	0.51	0.51	RF	165
Wynaad Laughingthrush*	-	-	-	-	-	0.34	-	-	-	-	0.25	0.34	0.41	RF	5
Yellow-browed Bulbul	-	-	0.85	0.76	1.61	1.36	0.34	0.85	2.09	1.33	1.72	1.36	1.49	RF	215
Ashy Prinia	-	-	-	-	-	-	0.13	-	-	-	-	-	-	OC	1
Asian Brown Flycatcher	-	-	-	0.06	-	-	0.08	0.04	-	-	-	-	-	OC	4
Black-rumped Flameback	-	-	0.42	-	0.17	-	0.25	-	-	-	0.03	-	-	OC	7
Black-shouldered Kite	-	-	-	-	-	-	0.08	-	-	-	-	-	-	OC	2
Blyth's Reed Warbler	1.27	0.91	1.49	0.83	0.21	0.59	1.91	0.38	0.03	-	0.06	-	0.08	OC	110
Booted Eagle	-	-	-	-	-	-	0.04	-	-	-	-	-	-	OC	1
Brown Shrike	-	-	-	-	0.04	-	0.34	0.08	-	-	-	-	-	OC	11
Brown-capped Pygmy Woodpecker	-	-	-	0.13	-	-	-	-	-	-	-	-	-	OC	1
Chestnut-headed Bee-Eater	-	-	-	-	-	-	-	-	-	0.23	-	0.21	-	OC	7
Chestnut-tailed Starling	0.95	-	-	-	-	-	-	-	-	-	-	-	-	OC	1
Common Hoopoe	-	-	-	-	-	-	0.13	-	-	-	-	-	-	OC	3
Common Iora	-	-	-	0.38	0.17	0.42	0.17	0.08	-	-	0.03	-	-	OC	14
Common Rosefinch	0.32	0.18	-	0.13	-	-	0.08	-	-	-	-	-	-	OC	4
Common Tailorbird	1.27	0.91	1.27	0.51	-	0.08	0.68	0.42	-	-	-	-	-	OC	33
Eurasian Golden Oriole	-	-	0.21	-	-	-	-	-	-	0.08	-	0.04	-	OC	5
Great Tit	-	-	-	-	-	-	-	-	-	-	0.06	-	-	OC	1
Greater Coucal	0.32	-	0.21	0.13	0.04	-	0.17	0.17	0.03	-	0.06	0.04	-	OC	17
Grey-breasted Prinia	-	-	-	-	-	-	0.25	-	-	-	-	-	-	OC	3
House Crow	-	0.18	-	0.19	-	-	-	-	-	-	-	-	-	OC	3
Jungle Myna	1.27	-	-	-	-	-	-	-	-	-	-	-	-	OC	3
Large-billed Crow	0.32	0.18	0.21	0.64	0.76	1.74	0.42	1.78	0.06	0.11	0.45	0.04	0.12	OC	62
Oriental Magpie Robin	-	0.36	-	-	-	0.13	0.13	-	-	-	-	-	-	OC	5
Plum-headed Parakeet	2.23	0.36	-	-	-	0.08	0.64	0.51	-	0.34	0.22	0.08	-	OC	29
Purple Sunbird	0.64	-	0.85	0.57	-	-	0.04	-	-	-	-	-	-	OC	10
Red-whiskered Bulbul	3.82	1.09	2.97	2.55	0.08	0.68	2.93	0.64	0.06	-	0.19	-	0.14	OC	93
Shikra	-	-	-	-	-	-	0.08	-	-	-	-	-	-	OC	1
Small Minivet	1.59	-	-	0.25	0.08	-	0.21	-	-	-	-	-	-	OC	6
Spotted Dove	-	0.36	-	-	-	-	-	-	-	-	-	-	-	OC	1
Streak-throated Woodpecker	0.64	-	-	-	-	-	-	0.08	-	-	-	-	-	OC	2
White-breasted Waterhen	-	-	-	0.06	-	-	-	-	-	-	-	-	-	OC	1
White-throated Kingfisher	-	-	-	-	-	-	0.08	-	-	-	-	-	-	OC	2